SPSE

Photographic
SCIENCE AND ENGINEERING

The Chemistry of Color Developers: Effect of EDTA and Iron on the Loss of Developer and Sulfite from Aerated Solution • *Paul M. Mader* 49

A Test Instrument for Small-Aperture Galvanometer Optics *John A. Stafford* 57

A Low-Intensity Ultraviolet Sensitometer *R. F. Newell* 61

Photographic Exposure Guides and Meters Part III — Actinometers • *E. P. Wightman* 64

Book and Journal Reviews 88

Technicalia Photographica • *Frank Smith* 92

1959 Annual Conference Notice 96

Volume 3 · Number 2

MARCH-APRIL · 1959

Editorial Policy

Photographic Science and Engineering is dedicated to the advancement of the knowledge and application of photography and other directly related sciences. Its pages are open to all who wish to report on new studies dealing with the theory of photosensitive systems, the design of photographic instruments and apparatus useful in the treatment of photographic materials, photographic optics and illuminants, the use of photography for scientific or engineering measurement or recording, and photographic instrumentation and data recording. Only original papers should be submitted except on special invitation.

Manuscripts should be typed double-spaced on white bond paper with $1^1/_4$-inch margins all around. Literature references should be exact, and should include titles of journals, names of authors, numbers of volumes and pages, and year of publication. Book references should include title of volume, names of authors, publisher, number of edition, year of publication, and chapter and pages cited.

Graphs, charts, and other line illustrations should conform to good usage such as given in the American Standards Association Document Y-15, "A Guide for Preparing Technical Illustrations for Publication and Projection." Continuous-tone photographs should be made on 8- by 10-inch glossy paper and should show pertinent image detail sufficiently clearly to permit reduction to fit a 3-inch column in this journal. All illustrations should be numbered in soft blue pencil on the back to correspond with captions typed on a separate page. Tables should also be submitted on separate pages appropriately identified. An abstract should accompany each manuscript.

Papers intended for publication should be submitted in duplicate to the editor, T. H. James, Research Laboratories, Eastman Kodak Co., Rochester 4, N.Y. All papers will be reviewed by members of the Editorial Review Board and if not accepted will be returned to the author. Published papers become the property of the Society and are protected by appropriate copyrights. Authors receive five copies of issues in which their contributions appear. Authors may order reprints of their papers at the time they return the galley proofs. The Society does not assume responsibility for material in transit, nor guarantee publication of unsolicited material.

Photographic
SCIENCE AND ENGINEERING

official publication of the
Society of Photographic Scientists and Engineers

March-April 1959

Volume 3, Number 2

EDITORIAL STAFF

T. H. James, *Editor*

Jennie H. Allen, *Managing Editor*

S. C. Goddard, *Feature Editor*

Frank Smith, *Feature Editor*

Robert H. Zappert, *Feature Editor*

Willard W. Van Allen, *Associate Editor*

EDITORIAL REVIEW BOARD

R. S. Barrows

R. Clark Jones

K. G. Leistner

J. A. Maurer

F. W. H. Mueller

H. F. Nitka

Thomas D. Smith

William West

Photographic Science and Engineering is published six times a year by the Society of Photographic Scientists and Engineers. The publication office is at 20th and Northampton Streets, Easton, Pa. Address correspondence to the Society at Box 1609, Main Post Office, Washington, D.C. Subscription to non-members of the Society, $8.00 per year, members $4.00; single copies, $2.00 each. The Society is not responsible for the accuracy of statements made by authors and does not necessarily subscribe to their views. Second-class mail privileges authorized at Easton, Pa. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122.

© Copyright 1959 by the Society of Photographic Scientists and Engineers, Inc. Permission to reprint any part of the contents, except in reviews and abstracts, must be obtained in writing from the Editorial Vice President.

PHOTOGRAPHIC SCIENCE AND ENGINEERING
Volume 3, Number 2, March-April 1959

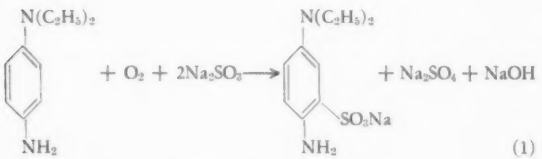
The Chemistry of Color Developers:

Effect of Ethylenediaminetetraacetic Acid and Iron on the Loss of Developing Agent and Sulfite from Aerated Solutions

PAUL M. MADER, *Research Laboratories, Eastman Kodak Company, Rochester, N.Y.*

When air was passed into a color developer containing p-amino-N,N-diethylaniline, sodium sulfite, and potassium carbonate, close to two moles of sulfite were lost for each mole of developer lost. If ethylenediaminetetraacetic acid (EDTA) was added, this ratio became lower (1.5) and the rate of loss of developing agent higher. Addition of very small amounts of ferric iron to the solution increased these effects of EDTA, and the use of purer chemicals decreased them. The conclusion is reached that traces of iron in the chemicals were responsible for the effects of EDTA in the solutions to which no iron was added. It is prcposed that EDTA exerts its effects by forming the ferric iron complex, which catalyzes the hydrogen peroxide–develcping agent reaction (demonstrated experimentally) and perhaps also the reaction of developing agent with oxygen. Hydrogen peroxide was formed in sufficient quantity during aeration to allow operation of the proposed mechanism.

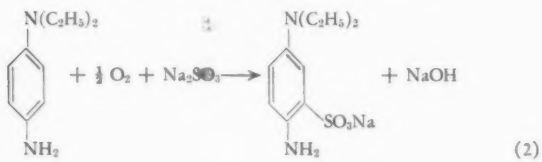
When air is passed into a color developer consisting of *p*-amino-N,N-diethylaniline, sodium sulfite, potassium carbonate, and water, very nearly two moles of sulfite are lost for each mole of developing agent lost.[1] The over-all stoichiometry for the reaction approximates:



(1)

This stoichiometry is maintained approximately, even though the initial concentrations of developing agent and sulfite are varied. The same stoichiometry has been found for hydroquinone developers.[2]

Several years ago it was reported[3] that addition of ethylenediaminetetraacetic acid (EDTA) to the color developer changed the reaction with air to:



(2)

Thus, only one mole of sulfite was lost for each mole of developing agent lost. In addition, EDTA increased the rate at which developing agent was lost.[4]

These interesting effects of EDTA were ascribed to traces of copper salts in the solutions.[3] It was suggested[4] that the sodium sulfate of reaction (1) resulted from the direct, copper-ion-catalyzed oxidation of sulfite by air. The shift to the stoichiometry of reaction (2) was believed to be due to complexing of the copper ion by the EDTA and the resultant elimination of the oxygen–sulfite reaction. Increase in rate of loss of developing agent was thought to be due to elimination of the oxygen–sulfite reaction, with the result that oxygen which would otherwise be used in this reaction would be diverted to the reaction with developing agent. The conclusion was reached that reaction (2) represents "the normal non-catalyzed course of autoxidation of color-developer solution containing sulfite."

This explanation of the effects of EDTA appears to be inadequate in that it does not take into consideration the hydrogen peroxide formed in the reaction of oxygen with developing agent. It seems unlikely, for example, that the sodium sulfate of reaction (1) results, as suggested, from direct, copper-catalyzed reaction of oxygen with sulfite. The stoichiometry of the reaction is better explained by assuming that the sulfate is formed through oxidation of the sulfite by the hydrogen peroxide. If the sulfate is formed in this way rather than through the direct oxygen–sulfite reaction, then obviously the change to the stoichiometry of reaction (2) caused by EDTA cannot be due to elimination of the oxygen–sulfite reaction, as was suggested. The experiments described in this paper were run in the hope that a more satisfactory explanation for the effects of EDTA might be obtained.

Communication No. 1987 from the Kodak Research Laboratories.
Received 13 November 1958.

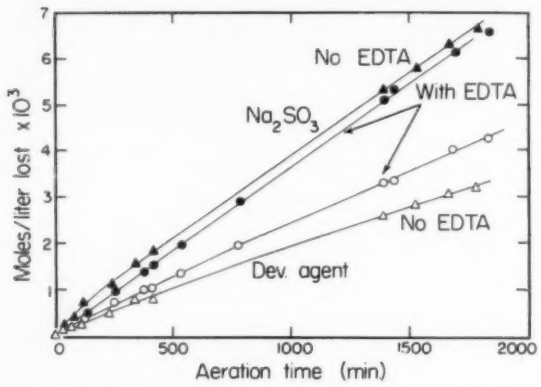


Fig. 1. Effect of EDTA on loss of developing agent and sulfite from aerated color developer.

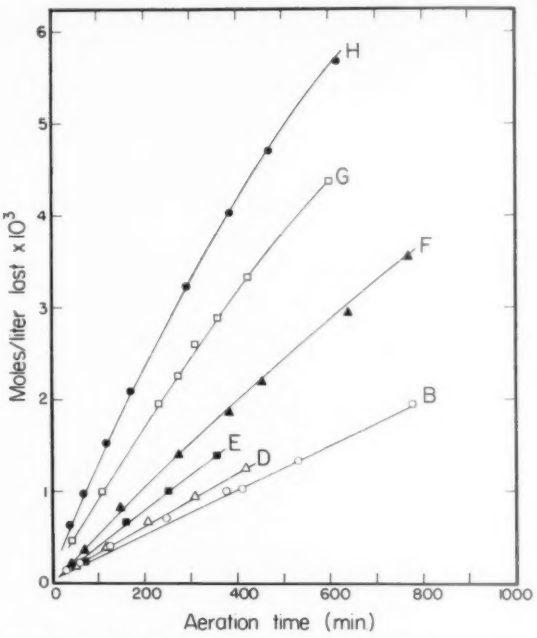


Fig. 2. Effect of ferric iron on loss of developing agent from aerated color developers containing EDTA. Grams per liter of iron added to the solutions: B, none; D, 5×10^{-5}; E, 1.4×10^{-4}; F, 3×10^{-4}; G, 10^{-3}; H, 2×10^{-3}.

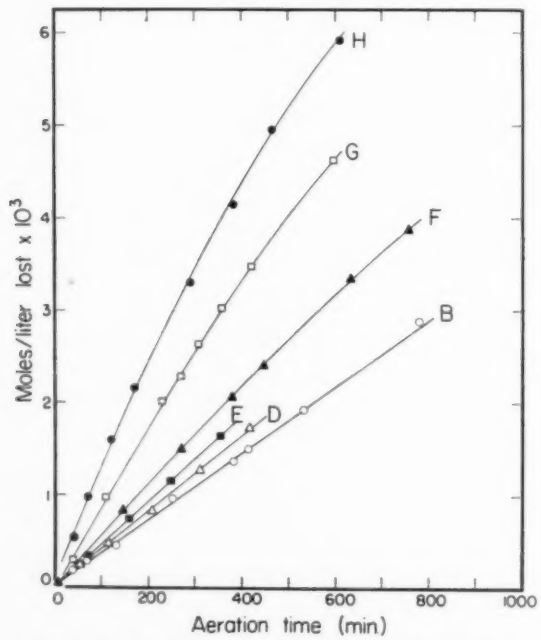


Fig. 3. Effect of ferric iron on loss of sulfite from aerated color developers containing EDTA. Grams per liter of iron added to the solutions: B, none; D, 5×10^{-5}; E, 1.4×10^{-4}; F, 3×10^{-4}; G, 10^{-3}; H, 2×10^{-3}.

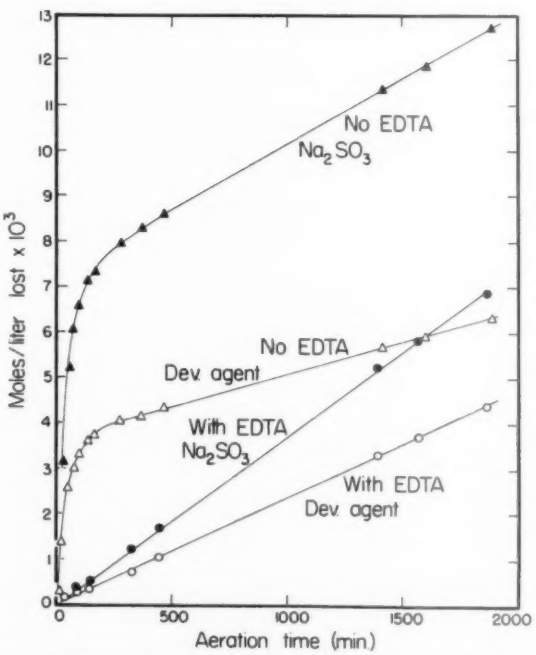


Fig. 4. Effect of EDTA on loss of developing agent and sulfite from color developer containing cupric copper (1.4×10^{-4} gram/liter).

Aeration Experiments

Air was passed into color developers at a rate sufficient to keep the solutions saturated with air. Temperature of the solutions was 24°C. From time to time, samples were removed and analyzed for developing agent and sulfite. In addition to the addenda listed in Table I, the solutions contained:

p-Amino-N,N-diethylaniline hydrochloride	0.56	g
Sodium sulfite	0.75	g
Potassium carbonate (anhydrous)	15	g
Water	300	ml

Experimental results are given in Figs. 1-4.

The molar ratios (R) of Na_2SO_3 lost to developing agent lost during aeration are given in Table I.

TABLE I

Developer Addenda and Molar Ratios (R) of Sodium Sulfite Lost to Developing Agent Lost

Solution	Metal Ion Added	Wt. of Metal Ion (g/l)	EDTA-Na_2 Added (g/l)	R
A	None	———	0	2.05
B	None	———	2	1.5
C	Fe^{+++}	2×10^{-3}	0	1.95
D	Fe^{+++}	5×10^{-5}	2	1.4
E	Fe^{+++}	1.4×10^{-4}	2	1.2
F	Fe^{+++}	3×10^{-4}	2	1.1
G	Fe^{+++}	10^{-3}	2	1.05
H	Fe^{+++}	2×10^{-3}	2	1.05
I	Cu^{++}	1.4×10^{-4}	0	2.0
J	Cu^{++}	1.4×10^{-4}	2	1.55
	Cr^{+++}, Co^{++}, Mn^{++}, Ni^{++}	10^{-3}*	0	1.2
L	Cr^{+++}, Co^{++}, Mn^{++}, Ni^{++}	10^{-3}*	2	1.35
M†	None	———	2	1.85

* One mg/liter of each of the four ions was added to the solution.
† Like solution B, except that purer ingredients were used.

Discussion of Aeration Experiments

As expected, Solution A gave an R value close to 2. However, when EDTA was put in the solution (Solution B), R did not drop to unity, as it had been reported[3] to do, but to 1.5. As previously observed,[4] an increase in the rate of loss of developing agent did occur (Fig. 1).

Why did R fall only to a value of 1.5 rather than to unity when EDTA was introduced into the solution? The results for Solutions D-H give a clue. It is seen that only 0.3 mg/liter of ferric iron needed to be added to the solution to cause R to fall to a value near unity. In the absence of EDTA, addition of iron had little effect on the value of R (Solution C). Thus, to explain the fact that the previous investigation[3] yielded a value of unity for R, while a value of 1.5 was observed here, it is sufficient to make the reasonable assumption that the chemicals used in the previous investigation contained a little more iron than the chemicals used here.

As shown in Figs. 2 and 3, addition of ferric iron to the EDTA-containing developer caused an increase in the rate of loss of developing agent and sulfite. The increase was not proportional to the amount of iron added but became less as the amount of iron added became greater. In the absence of EDTA, addition of 2 mg/liter of ferric iron caused less than 5% increase in the rate (Solution C).

Copper had an effect on the course of the reactions entirely different from that of iron (Fig. 4). In the presence of EDTA, addition of 1.4×10^{-4} gram/liter of cupric ion had no significant effect on either the value of R or the rates of loss of developing agent and sulfite. In the absence of EDTA, addition of copper gave a pronounced catalysis, but only during the first part of the aeration period, and the value of R (2.00) was the same as in the absence of copper, even during the catalytic period.

The results with Solutions K and L (Fig. 5) indicate that metals other than iron and copper also exert catalytic effects. In the presence of EDTA, the combination of metals added to the solution gave effects similar to those shown by iron (increase in the rate of loss of developing agent and decrease in the value of R). However, the magnitude of the effects was considerably less than given by 1 mg/liter of iron alone. In absence of EDTA, the effects on the rate and on R were even greater than in the presence of EDTA. In this respect, the effect of this combination of metals differed from that of iron, which had almost no effect in the absence of EDTA.

The experimental results for the solutions containing added metal ions strongly suggest that the drop in R from 2 to 1.5 and the increase in the rate of loss of developing agent noted when EDTA was added to Solution A (giving Solution B) were due to traces of metallic impurities. This idea is supported by the results for Solution M, which was prepared using purer chemicals than those used in Solution B. Solution M gave an R value nearer to 2 than that for Solution B, and Fig. 6 shows that the rate of loss of

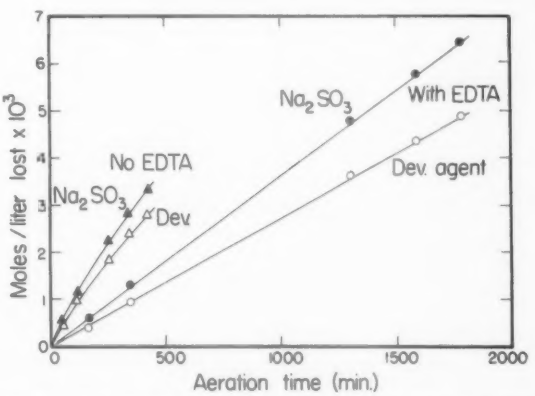


Fig. 5. Effect of EDTA on loss of developing agent and sulfite from color developer containing Cr^{+++}, Co^{++}, Mn^{++}, and Ni^{++} salts (10^{-3} gram/liter of each metal).

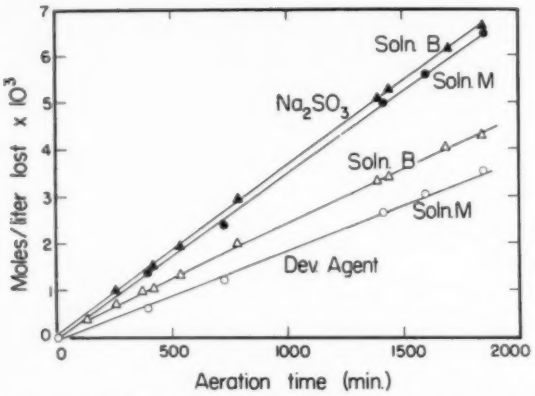


Fig. 6. Effect of using purified chemicals on loss of developing agent and sulfite from color developer. Solution B: chemicals not specially purified; Solution M: chemicals purified.

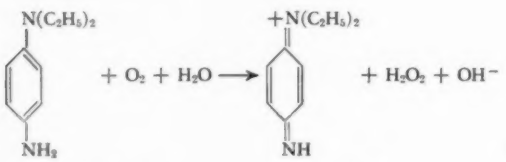
developing agent was less than for Solution B, being close to the rate of Solution A.

It is most likely that the impurity responsible for the effects of EDTA in Solution B was ferric iron. Indeed, traces of iron were detected spectrographically in the reagent-grade potassium carbonate used in Solution B. The level of iron was probably sufficient to account for the observed effects. Spectrographic evidence indicated that the iron level in the carbonate used in Solution M was approximately one-fifth of that in the reagent-grade carbonate.

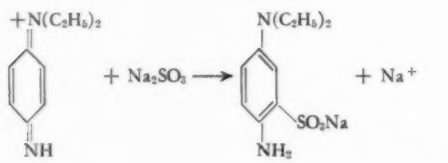
It seems reasonable to assume that, if sufficiently pure chemicals were used in preparing the color developer, addition of EDTA would have no effect either on the value of *R* or on the rate of loss of developing agent. The conclusion is reached that reaction (1), *not* reaction (2), represents the normal noncatalyzed course of autoxidation of color developers containing sulfite.

Mechanism of the Effect of Iron and EDTA on Autoxidation of Color-Developer Solutions

The stoichiometry of reaction (1) has been explained for *p*-amino-N,N-diethylaniline[5] and hydroquinone[2] developers as being due to a summation of the reactions:



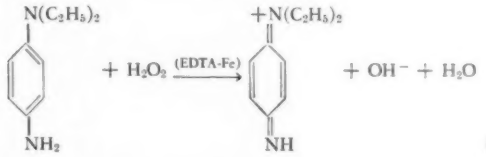
(3)



(4)

$$H_2O_2 + Na_2SO_3 \longrightarrow H_2O + Na_2SO_4 \qquad (5)$$

How might EDTA and iron alter this mechanism so as to give the stoichiometry of reaction (2)? One possible explanation is that the ferric ion–EDTA complex (EDTA-Fe) catalyzes the reaction between hydrogen peroxide and developing agent:



(6)

Suppose that reaction (6) is so much faster than reaction (5) that all of the peroxide formed in reaction (3) reacts according to (6). No sulfate will be formed, and the over-all stoichiometry will be that of reaction (2). Also, the rate of loss of developing agent will be doubled. The fact that the rate can be more than doubled if sufficient iron is added to the EDTA-containing developer (Fig. 2) can be explained by assuming that reaction (3) is also catalyzed by EDTA-Fe.

In the experiments to be described next, this postulated mechanism has been substantiated in two ways: First, it is shown that hydrogen peroxide does build up in an aerated, EDTA-free developer to about the extent predicted by reactions (3) and (5). Second, it is shown that EDTA-Fe does catalyze the reaction of hydrogen peroxide with the developing agent and to a sufficient extent to cause reaction (6) to predominate over reaction (5).

Formation of Hydrogen Peroxide in Aerated Color-Developer Solutions

The solutions aerated (at 25°C) were identical to Solution A, except that they contained less sodium sulfite so that measurable concentrations of hydrogen peroxide would accumulate. Solution N contained 0.2 gram/liter of sodium sulfite, Solution O contained 0.5 gram/liter. Polarograms of samples of the aerated solutions were obtained before and after addition to them of a high concentration of sodium sulfite (to remove H_2O_2), and the second polarographic waves were subtracted from the first. That the "difference waves" so obtained were due to hydrogen peroxide was indicated by the good agreement between these waves and the hydrogen peroxide wave (see Fig. 7, for example). The concentration of hydrogen peroxide in the samples was calculated from the height of the difference waves. The values are plotted in Fig. 8. (This method of difference waves had to be used, since there was a slow accumulation in the aerated solutions of a sulfite-resistant substance giving a polarographic wave near to that of hydrogen peroxide.)

For comparison with these experimental hydrogen peroxide concentrations, the theoretical concentrations expected on the basis of reactions (3) and (5) were calculated as follows: At any instant during

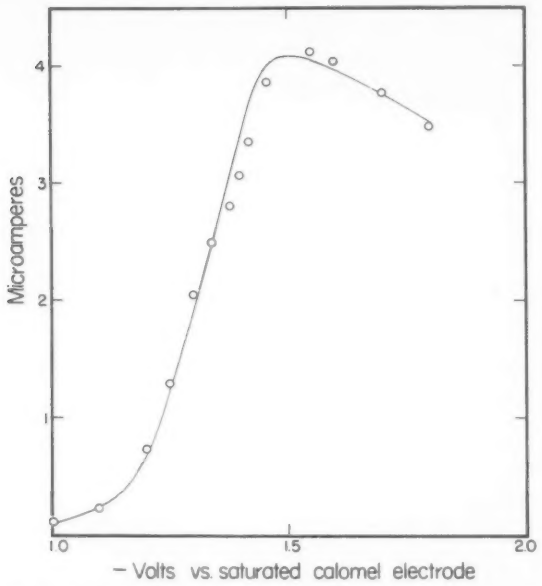


Fig. 7. Polarographic evidence for formation of hydrogen peroxide in aerated color developer, N. Curve: wave for hydrogen peroxide solution containing 1.87 grams/liter *p*-amino-N,N-diethylaniline hydrochloride and 50 grams/liter K_2CO_3; points: data for the difference wave of 146-min aerated developer solution, N.

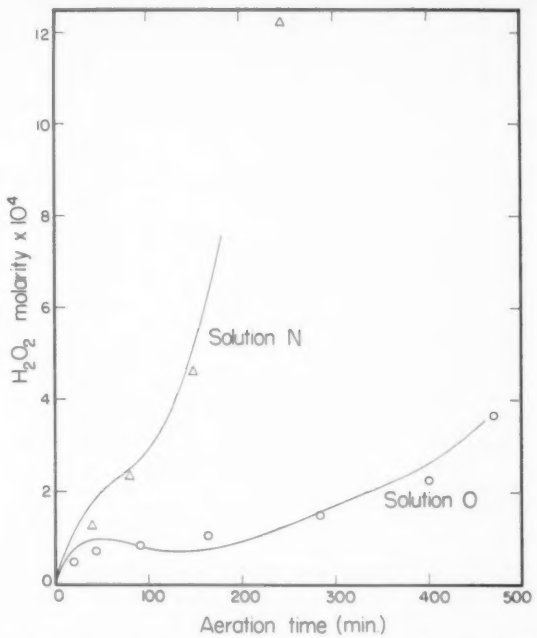


Fig. 8. Concentration of hydrogen peroxide in aerated developers as a function of aeration time. Curves: theoretical values; points: experimental values.

aeration the net rate of increase in hydrogen peroxide concentration is the difference between the rate at which peroxide is formed in reaction (3) and the rate at which it is consumed in reaction (5).

$$\frac{d(H_2O_2)}{dt} = -\frac{d(\text{dev})}{dt} - k_2(H_2O_2)\,(SO_3^{=}), \quad (7)$$

where (dev) is the concentration of developing agent, and k_2 is the second-order rate constant for reaction (5). Integration of Eq. (7) gives

$$(H_2O_2) = -e^{-\int_0^\tau k_2(SO_3^{=})dt} \cdot \int_0^\tau \left[\frac{d(\text{dev})}{dt}\right] e^{\int_0^\tau k_2(SO_3^{=})dt} \cdot dt \quad (8)$$

where (H_2O_2) is concentration of hydrogen peroxide at aeration time, τ. To evaluate this expression, it was necessary to know $(SO_3^{=})$ and $d(\text{dev})/dt$ as functions of time and the value of k_2. The functional relationships needed were obtained experimentally by repeating the aeration of Solutions N and O and analyzing from time to time for developing agent and sulfite. The value of k_2 (10.5 l. mole^{-1}min^{-1}) was determined by the method described previously.[6] This k_2 determination was made using a solution having the same potassium carbonate concentration and pH value (11.23 at 25.0°C, achieved by addition of hydrochloric acid) as Solutions N and O. Evaluation of Eq. (8) was accomplished by graphical integrations. Results are given as smooth curves in Fig. 8. Agreement between experimental points and the theoretical curves is fairly good, lending support to the theory that hydrogen peroxide is formed and consumed in accordance with reactions (3) and (5).

Catalysis of the Hydrogen Peroxide–Developing Agent Reaction by EDTA-Fe

Evidence for the catalysis of the hydrogen peroxide–developing agent reaction by EDTA-Fe was obtained in a qualitative experiment, using the polarograph as a means of observing changes in peroxide concentration. It was found that hydrogen peroxide disappeared only slowly in the presence of either developing agent or EDTA-Fe alone. In the presence of both, however, the peroxide disappeared quite quickly. The purple-gray color which developed indicated that the developing agent was undergoing oxidation. The developing agent was not oxidized to any appreciable extent by the EDTA-Fe alone.

Reaction of Color-Developer Solutions with Hydrogen Peroxide

To ascertain the importance of reaction (6) relative to reaction (5), hydrogen peroxide was added slowly to color developers swept constantly by a slow stream of nitrogen. For each solution, the rate of addition of peroxide was nearly equal to the rate at which

peroxide presumably formed during aeration of the solution. With one exception (Solution P), the solutions had the same composition as solutions used for aeration experiments and are identified by the same letters in Table II as in Table I. Solution P was like Solution B, except that 0.5 mg/liter of ferric iron was added. The temperature of the solutions was not held constant during peroxide addition but varied between 25° and 27°C. The solutions were analyzed several times during peroxide addition to determine how much developing agent and sulfite were lost. Results are given in Table II.

TABLE II
Reaction of Developers with Hydrogen Peroxide

Solution	Rate of H_2O_2 Addition $\times 10^4$ (moles l^{-1} min^{-1})	Moles Lost per Mole H_2O_2 Added	
		Developing Agent	Na_2SO_3
A	2.0	0.05	0.92
B	2.0	0.51	1.00
M	2.0	0.28	0.93
P	3.6	0.94	0.96

It is seen that in absence of EDTA (Solution A), reaction (6) was of minor importance. Presence of EDTA (Solution B) did cause reaction (6) to compete noticeably with reaction (5), and, indeed, when 0.5 mg/liter of ferric iron was added to the EDTA-containing developer (Solution P), reaction (6) greatly predominated. Use of purer chemicals (Solution M) decreased the importance of reaction (6). These results are in good qualitative agreement with the hypothesis that EDTA and iron decrease the value of R by increasing the rate of reaction (6).

It is possible, by using the values in the third column of Table II, to calculate what the expected R values would be if reaction (6) occurred to the same extent relative to reaction (5) during the aeration experiments as in the hydrogen peroxide-addition experiments. The assumption is made that no reactions other than (3) through (6) occurred in the solutions. Then

$$R = \frac{2}{1+f},$$

where f is the fraction of the peroxide reacting by (6), i.e., the values from the third column of Table II. The calculated R values, along with the observed values from Table I, are given in Table III.

TABLE III
Comparison of Calculated and Experimental R Values

Solution	R (calcd.)	R (obs.)
A	1.90	2.05
B	1.33	1.50
M	1.56	1.85
P	1.03	1.10 (Solution F)

The calculated and experimental R values are in the same order but do not agree very closely in magnitude, perhaps because of experimental errors and the occurrence of reactions in addition to reactions (3) through (6). Although reactions (3) through (6) are probably the most important, others certainly take place. The fact that the aerated solutions became colored is one indication of such additional reactions.

On the basis of reactions (4) through (6), it would be expected that the sulfite-consumption values in the fourth column of Table II would all be unity. Whether the peroxide reacts directly with sulfite or with developing agent to give a diimine, which, in turn, reacts with sulfite, the result is that one mole of sulfite is lost for each mole of peroxide which reacts. The values are close to unity.

Conclusions

1. The fact that EDTA was observed to increase the rate and alter the stoichiometry of the reaction of air with the color developer studied is most likely due to traces of ferric iron in the solution.
2. EDTA exerts its effect on the stoichiometry of the reaction by uniting with the traces of ferric iron in the solution, forming a complex which catalyzes the otherwise unimportant reaction between the developing agent and hydrogen peroxide. This hydrogen peroxide is a product of the reaction between the developing agent and oxygen.
3. The increase in the rate of loss of developing agent caused by addition of EDTA to the solution is due to catalysis of both the hydrogen peroxide–developing agent and oxygen–developing agent reactions by the EDTA–ferric iron complex.
4. In the absence of impurities, the stoichiometry of the reaction of the color-developer solution with air should maintain its normal value (close to two moles of sulfite consumed for each mole of developing agent lost) when EDTA is added to the solution.

Appendix—Experimental Details

Materials

Reagent-grade chemicals were obtained from the General Chemical Division of Allied Chemical and Dye Corporation.

Potassium carbonate was purified as follows: The reagent-grade potassium carbonate (50 g) was dissolved in a mixture of 20 ml of water plus 20 ml of a solution obtained by dissolving 1.84 g of reagent-grade potassium hydroxide in 200 ml of water. To this solution, contained in a platinum-lined beaker, there was added quickly, with stirring, a solution of 2.00 g of $Mg(NO_3)_2 \cdot 6H_2O$ in 26 ml of water. The precipitate, which contained much of the iron originally present in the solution, was allowed to settle two days, and the clear solution containing the purified potassium carbonate was decanted into a polyethylene bottle. Double-distilled water was used

throughout. All vessels were cleaned with concentrated hydrochloric acid and rinsed with double-distilled water.

Purified and reagent-grades of EDTA Na_2 (Sequestrene NA2) were obtained from the Geigy Chemical Corporation.

The *p*-amino-N,N-diethylaniline hydrochloride had the following analysis:

Calcd.: C, 59.84; H, 8.54; N, 13.96; Cl, 17.66. Found: C, 59.5; H, 8.3; N, 14.2; Cl, 17.3.

The heavy-metal salts added to the developers were reagent grades of $FeCl_3 \cdot 6H_2O$, $CuCl_2 \cdot 2H_2O$, $Cr(NO_3)_3 \cdot 9H_2O$, $Co(NO_3)_2 \cdot 6H_2O$, $MnSO_4 \cdot H_2O$, and $Ni(NO_3)_2 \cdot 6H_2O$.

Solutions

All solutions except M were prepared using reagent-grade Na_2SO_3 (specified maximum iron content: 0.001%), reagent-grade K_2CO_3 (specified maximum iron content: 0.0005%), purified grade of Sequestrene NA2 (if present), and single-distilled water.

Solution M was prepared using reagent-grade Na_2SO_3 having a specified maximum iron content of 0.0005%, purified K_2CO_3, reagent-grade Sequestrene NA2, and double-distilled water. The purified K_2CO_3 was introduced into the solution in the form of the concentrated solution obtained in the purification procedure already described.

Solutions for the aeration experiments were prepared as follows: The water was divided in two parts. If EDTA was used, about half was dissolved in one part and the rest in the other part. The K_2CO_3 was dissolved in one part and then the Na_2SO_3 and developing agent were quickly dissolved in the other part. The carbonate solution was added rapidly to the developing agent–sulfite solution and aeration was started immediately. When heavy-metal salts were used, they were incorporated in the water or in water plus EDTA Na_2 before the other ingredients were dissolved. A different procedure was used for Solution C. First, the carbonate was dissolved in the entire quantity of water containing the desired quantity of added ferric salt. Then, after about 15 min, the sulfite was dissolved and quickly thereafter the developing agent.

Solutions for H_2O_2-addition experiments were prepared by dissolving the ingredients in the following order in the total quantity of water: EDTA Na_2 (if present); sulfite; developing agent; carbonate. The iron of Solution P was introduced as a dilute solution of the EDTA complex after the developer solution had been freed of air with N_2.

Analytical Procedures

Sulfite. A 1-ml sample of the developer was pipetted into a mixture of 5 ml of 0.01 *N* iodine solution (1% in KI) and 5 ml of 1.4 *N* H_2SO_4. The excess iodine was titrated with 0.1 *N* $Na_2S_2O_3$, using an ultramicroburet. Fisher Thiodene indicator was used.

The presence of H_2O_2 in the developers caused some error in the sulfite determinations, since the peroxide reacted slowly with the iodide, producing iodine. Also, part of the peroxide may have reacted with the sulfite in the sample as it was added to the acidic iodine – iodide solution. The iodide – peroxide reaction caused the endpoint of the titration to shift slowly, requiring addition of more thiosulfate. That this shift was actually caused by peroxide and not by atmospheric oxygen was shown by comparing the rate of the shift with that obtained when hydrogen peroxide was added to a titrated solution from which all the peroxide originally present had disappeared. The rates were identical and much larger than the rate caused by air. The errors due to peroxide were generally small because the peroxide concentration in the aerated developers was so low. For solutions N and O, however, appreciable amounts of peroxide accumulated, owing to the low sulfite concentrations. In titrating samples of these two solutions, two drops of 1% ammonium molybdate solution were added to the solutions titrated to accelerate the peroxide–iodide reaction. The amount of the thiosulfate used then gave a measure of the difference between the sulfite and the peroxide concentrations existing in the aerated developer at the time the sample was removed. To obtain the value of the sulfite concentration, the peroxide concentration determined polarographically was added to this difference value.

Developing Agent. A 3-ml sample of the developer was pipetted into 10 ml of ligroin (E.K.Co. P513) and the mixture was shaken 1 min. After it separated, the aqueous phase was drawn off and discarded. Three ml of the ligroin phase was pipetted into a mixture of *ca.* 7.5 ml of 1.2 *N* H_2SO_4 and 7.5 ml of 1.67×10^{-4} *M* ferroin contained in a 50-ml beaker. The mixture was stirred magnetically and titrated, using 0.05 *N* cerate solution, delivered from a microburet below the surface of the aqueous phase. The endpoint was detected potentiometrically (at 0.72 volt) with platinum and calomel electrodes. The ferroin served to accelerate the cerate–developing agent reaction, thus allowing the endpoint to be more quickly and reproducibly obtained.

Since extraction of developing agent into the ligroin was not quite complete at equilibrium, the analytical procedure was calibrated, using developers containing known amounts of developing agent.

Hydrogen Peroxide. Solutions N and O were analyzed for peroxide as follows: A 10-ml sample was placed in the polarograph at a recorded time, *t*, and swept with Linde pure nitrogen for 3 min. Then the slowly decreasing* polarographic current was recorded for about 2 min at −1.5 volts *vs.* the saturated calomel electrode. The current at time *t*, needed for calculating the H_2O_2 concentration at that time, was obtained by extrapolating the slowly decreasing current back to time *t*. Next the current was recorded at other

* The current decreases, owing to reaction of the H_2O_2 with the sulfite in the sample.

potentials, so that the polarographic wave might be constructed. These current values were corrected for the decrease in current which occurred during their determination. To remove all H_2O_2 from the solution, 1.1 ml of a solution 12% in Na_2SO_3 and 0.04% in EDTA–tetrasodium salt was added. After several minutes, when the absence of any further decrease in polarographic current indicated that all peroxide had reacted with the sulfite, the current was again read at −1.5 volts and the value was corrected for the dilution resulting from addition of the sulfite solution. This corrected value was then subtracted from the original extrapolated (to time t) value to obtain a value for that part of the polarographic current which had been due to H_2O_2. By comparing this difference value with currents given by known concentrations of H_2O_2 in a similar medium, the H_2O_2 concentration in the sample could be calculated. Next, the polarographic currents for the now H_2O_2-free sample were recorded at those same potentials at which the current had been measured before addition of the sulfite solution. These current values were corrected for dilution by the sulfite solution and subtracted from the current values obtained before sulfite addition, giving polarographic wave data for the H_2O_2 originally present in the sample.

Aeration Procedure

The developer was placed in a 500-ml glass cylinder in a constant-temperature ($T \pm 0.5$°C) water bath. Air, passed first through a flowmeter and 300 ml of 5% K_2CO_3 solution at the same temperature as the developer, was introduced into the developer through a coarse, sintered-glass plug. The rate of air flow was 150 ml/min. Increasing the rate twofold did not change the rates at which developing agent and sulfite were lost from the solutions.

Addition of Hydrogen Peroxide to Developers

The solution (100 ml) was placed in a glass cylinder containing a magnetic stirring bar and closed at the top by a rubber stopper. The stopper was fitted with glass tubes for introducing nitrogen above and below the surface of the solution, a capillary tube for introducing H_2O_2 solution, a nitrogen-exit tube, and an opening (stoppered) through which samples could be removed. A coarse, sintered-glass plug was sealed at the end of the nitrogen-input tube dipping beneath the surface of the solution.

The solution was swept free of air with nitrogen, which was first passed through 300 ml of a solution containing 15 g of K_2CO_3 and about 2 g of pyrogallol. After about 45 min, the rate of nitrogen flow was reduced to about 25 ml/min and allowed to flow through the solution at this rate during the remainder of the experiment. During removal of the samples, which were drawn up into a pipettlike vessel, a rather rapid flow of nitrogen was introduced above the surface of the solution.

The magnetic stirrer was started, the first sample was removed for analysis, and immediately the introduction of H_2O_2 solution was started. The H_2O_2 solution was introduced into the capillary delivery tube from a motor-driven, 3-ml glass syringe with a delivery rate of 3.1×10^{-3} ml/min. Peroxide solutions having concentrations giving the desired rates of addition of peroxide were prepared by diluting a 26% H_2O_2 solution, which was analyzed iodometrically. Samples of the developer were removed for developing agent and sulfite analyses during the course of H_2O_2 addition. Each sample had a volume of 5.0 ml. The total number of samples, including the first sample taken before start of H_2O_2 addition, was 4.

The losses (in moles) of developing agent and sulfite which had occurred as a result of H_2O_2 addition between the start of H_2O_2 addition and the times the samples were removed were calculated from the concentration of developing agent and sulfite found in the samples. These calculations were complicated by the fact that account had to be taken of the dilution of the developer by the H_2O_2 solution added and of the change in volume of the solution resulting from removal of samples. The equation used was

$$L_m = (C_o - C_m)(V_o - V_s) - V_s\left[\sum_{2}^{m-1} C_n - (m-2)C_m\right] - C_m v_m \quad (10)$$

where: L_m = loss of sulfite or developing agent (moles) at time mth sample taken; C_o = initial concentration (moles/liter); C_m = concentration in mth sample; V_o = initial volume of solution (liters); V_s = sample volume (liters); (All samples must have the same volume for the equation to apply.) and v_m = total volume of H_2O_2 solution delivered between start of reaction and time the mth sample was taken (in liters). The term $\sum_{2}^{m-1} C_n$ is the sum of concentration values for all samples from the second ($m = 2$) up to the $m - 1$th.

For each experiment, the L_m values were plotted *vs.* the corresponding amounts (moles) of H_2O_2 added. The slopes of the least-squares straight lines through the resulting sets of points are given in the third and fourth columns of Table II. From the deviation of the points from the straight lines, it was calculated that the probable error in the slope values due to random errors is no greater than ±0.03.

References

1. Meyer, K., and Brune, W., *Z. wiss. Phot.*, *46:* 135 (1951).
2. Mees, C. E. K., *The Theory of the Photographic Process*, rev. ed., The Macmillan Co., New York, 1954, p. 561.
3. Meyer, K., and Roth, L., *Z. wiss. Phot.*, *49:* 10 (1954).
4. Meyer, K., *Bild und Ton*, *7:* 69 (1954).
5. Brune, W., and Kronacher, U., *Z. wiss. Phot.*, *48:* 6 (1953).
6. Mader, P. M., *J. Am. Chem. Soc.*, *80:* 2634 (1958).

PHOTOGRAPHIC SCIENCE AND ENGINEERING
Volume 3, Number 2, March-April 1959

A Test Instrument for Small-Aperture Galvanometer Optics

JOHN A. STAFFORD, *Schlumberger Well Surveying Corporation, Houston, Texas*

This paper describes an instrument which combines the technique of oblique-incidence photography with means for compensating for astigmatism, changing scale, and image intensity gradient to determine the quality and focal length of oscillograph galvanometer optics having a depth of focus of the order of ±100 mm. The ability of the instrument to determine focal length and to diagnose the general quality of such optics is illustrated by photographs made with the device. Also, the effects of malfocus and lens aberrations on the quality of oscillograph record traces are illustrated.

Information from an array of instruments traversing an oil well borehole usually is recorded by means of a specialized form of oscillograph. This device moves photosensitive film at a speed having a determined ratio with the progress of the sensing instruments in the hole. The electrical signals from those instruments activate moving mirror galvanometers which, in turn, deflect focused spots of light across the film to transcribe the electrical signals into the form of an autographic record known as a well log.

Obviously, the rate at which each rectangular spot travels across the film surface is, effectively, the inverse equivalent of the exposure time for each portion of the trace made by that spot. Moreover, in some cases, this spot velocity for a single trace may vary from a minimum rate of 1 in./min (the film travel rate only) to rates of the order of 1000 in./min resulting from transient signal excursions of the spot across the film.

With such a range of exposure time it becomes evident that if the spot has sufficient light intensity to expose the film during the high rates of travel, the trace is subject to gross over-exposure while it is less active. As a result, the overexposed portions of each trace are undesirably smeared by the actions of:

a. Film halation, which is minimized by antihalation backing on the film, and
b. The spread function of energy distribution in the spot which can be minimized by accurate focus and reduction of various aberrations of the galvanometer optics.

Since trace spreading is a detriment to the appearance of, and the accurate reduction of data from, the log it is advantageous to control, by inspection, the responsible qualities of the galvanometer optics.

Presented at the Annual Conference, Rochester, N.Y., 10 October 1958. Received 12 September 1958.

For the particular case in point, experience has proven that direct visual inspection of the spot image is not sufficiently critical. Since the correct image distance of the galvanometer optics is 515 mm and the galvanometer mirror is only 2 mm wide, the nominal depth of focus is of the order of ±100 mm. Measurements of the distance of best focus, by observing the image with magnification on a ground glass screen, have been found to vary as much as ±50 mm with different observers. Also, the presence of aberrations which are sufficient to cause abnormal trace spreading on the film by overexposure are virtually undetectable, even with devices which utilize the Ronchi test technique.

To meet the need for critical inspection of large quantities of galvanometers, a device was constructed which subjects the galvanometers to the same optical environment as does the oscillograph in which they are to be used. Under such environment, a deliberate amount of overexposure is employed to amplify and diagnose the optical shortcomings of the galvanometers.

Description

Optical Layout

Figure 1 shows the optical layout of the test instrument. The galvanometer lamp filament is imaged at the galvanometer mirror by means of a collector lens. A triple line object located immediately in front of the collector lens is, in turn, imaged at the oblique film plane by the galvanometer optics.

Astigmatism Compensation

Since the object is extra-axial, and noticeable astigmatism is inherent in the galvanometer optics, this is taken into account by sloping the object at an angle which compromises the sagittal astigmatism curve as referenced to the object plane. Thus, the

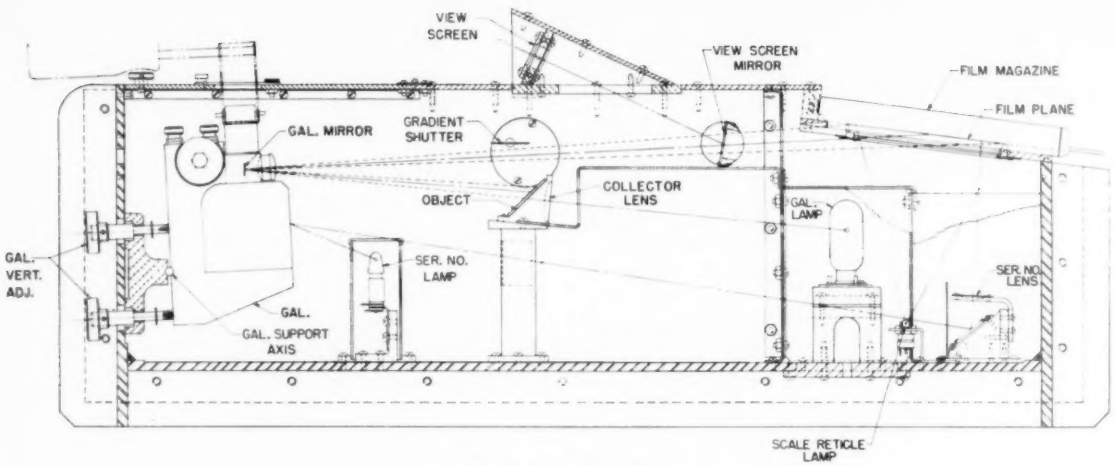


Fig. 1. Optical layout.

vertical line images at a plane perpendicular to the image axis and at the correct image distance have virtually equal focus throughout their length.

Scale Change Compensation

If the object lines were parallel and of uniform width, the oblique angle of image interception would cause the images of the lines to converge and taper. Accordingly, the lines in the object were designed to diverge and taper in such a way that their images appear parallel and uniform in width. Figure 2 is an enlarged view of the object film. This film was made by photographing, at a calculated angle, parallel tracks milled into a large sheet of black-and white laminated plastic. The track widths of the original were ten times the object line widths at the center. Multiple contact printing of the original negative produced the desired high density contrast of the final object film. The purpose of the lateral marks on either side of the object lines center will be mentioned later.

Intensity Gradient Compensation

Next it was recognized that the scale change compensation would result in an undesired gradient of illumination along the sloped image intercept. To compensate for this, a rather simple "gradient shutter" was employed. The shutter consists of a flat vane, rotated at the rate of 60 rpm by means of a synchronous clock motor. Figure 3 illustrates the vertical interference gradient as a function of time and how the interference is confined to the most linear portion of the sinusoidal function. By choice of the vane length and the distance of the vane axis from the top of the beam, the desired compensation gradient was obtained. Since the rotational speed provides 60 interferences for each exposure, it is of little importance whether the first or last interferences of the exposure are complete.

Image Positioning

The image beam is adjusted vertically by tilting the galvanometer, such that the center of the image

Fig. 2. Normal view of object (enlarged).

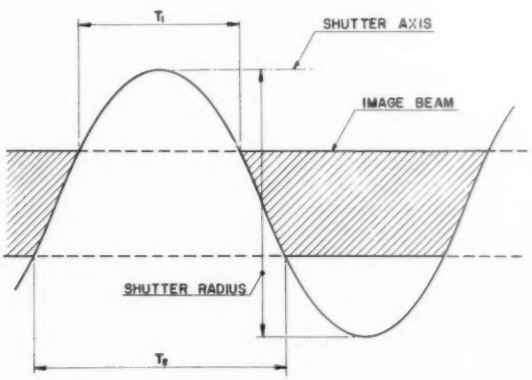


Fig. 3. Interference function of intensity gradient shutter.

length is located at the 515-mm image distance on the film plane. Also, by rotating the galvanometer barrel, the image is centered transversely on the film plane. Both of these positions are made visible to the operator by a semitransparent mirror and ground-glass view screen which has horizontal and vertical target lines. The vertical adjustment is correct when the two horizontal line images are centered on the horizontal target line. The horizontal projections are colored by a red gelatin filter at the object to prevent their being photographed.

Image Distance Scale

An image distance scale is imposed on each photograph by a scale reticle located near the film plane and projected by a grain-of-wheat lamp located near the base of the instrument. The slight enlargement due to this projection is compensated by appropriate compression of the scale reticle length.

Identification Number

To allow a number of test photos to be batch processed without losing identity, the serial number of each galvanometer is photographed on its respective film. This is accomplished by illuminating the front of the galvanometer magnet on which the serial number has been painted in white. A mirror and lens arrangement below the film form a correct reading image of the number on the film.

Miscellaneous

The film magazine employed is a commercially available item which automatically "shuffles" six film holders, presenting each film in sequence and covering

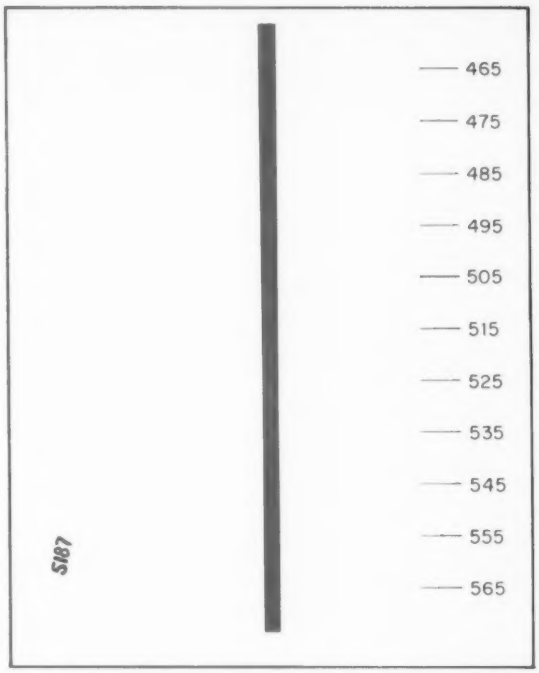


Fig. 4. Test record, typical of optics having good focus adjustment and quality.

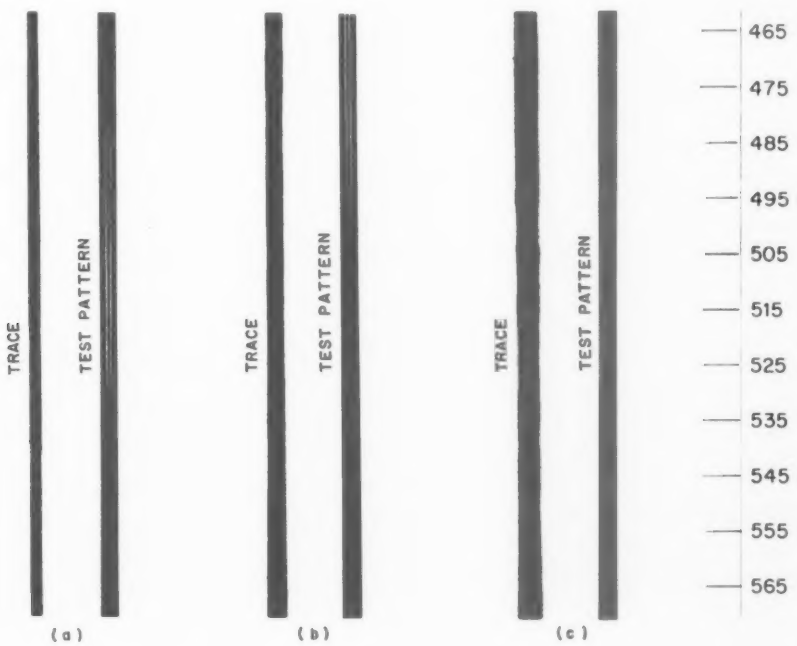


Fig. 5. Composite of overexposed oscillograph traces and test patterns for three cases: (a) good focus adjustment and quality, (b) focus adjustment out of tolerance, and (c) poor optical quality.

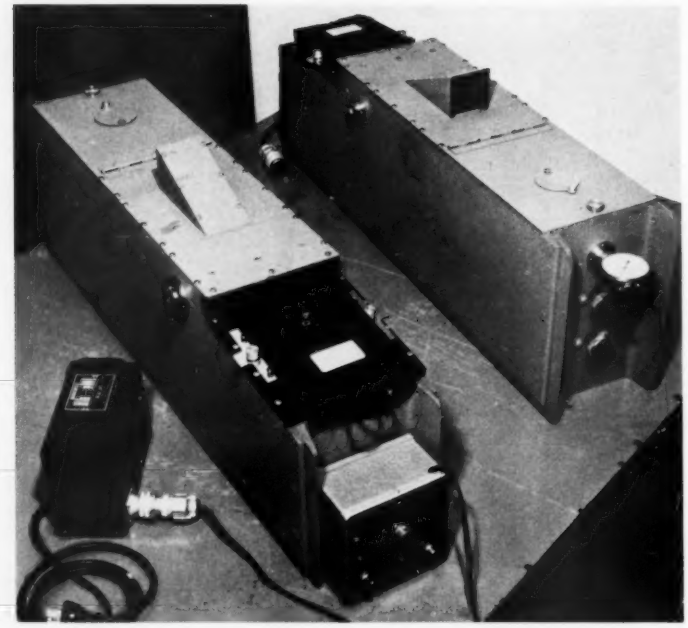


Fig. 6. "Twin" test instruments in use by the supplier and the purchaser.

each with a shutter between presentations. External indicators reveal the sequential number of the film being presented and whether or not it is covered. Equal exposure intensity and time for each test are insured by a voltage regulator and an interval timer which turns the lamp on and off for the film exposure. An override switch allows centering adjustments to be made, with the film shutter closed, prior to the exposure. Development is also controlled closely by insistance on fresh developer and rigid adherence to time and temperature directions.

Performance

By photographing the triple line object at an oblique angle, the device produces a record which represents the image quality over a distance span of 100 mm, centered at the ideal image distance. A typical test photograph, representing a galvanometer with good focus adjustment and good optical quality, is shown in Fig. 4.

Overexposure causes the three line images to converge at equal distances from the po'nt of best focus. Thus, by reference to the image distance scale imposed on each test photograph and with knowledge of the object distance, the focal length can be accurately determined. Also, the width and clarity of the areas between the line images at the point of best focus reveals the extent of abnormal image spread due to aberrations.

In this particular case, the images converge at 485 and 540 mm, indicating that this galvanometer has best focus at 513 mm. The clarity of the image at the center reveals the quality of the optics to be good.

As with any quality test, some reasonable latitude of tolerance should be given. Experience showed that with 30-sec exposure, any galvanometer which produced a test pattern having distinct separation of the lines at the 515-mm image distance would produce acceptable trace quality in the recorders. Thus, quality acceptance or rejection is a matter of "go or no-go" as determined immediately from the test film.

Figure 5 is a composite of three different test patterns and examples of an overexposed oscillograph trace produced by each of the galvanometers represented. Galvanometer (a) has acceptable focus and good optical quality. The trace produced by this galvanometer, although widened somewhat, has retained reasonably good edge definition. Galvanometer (b) has unacceptable (short) focus but good optical quality. The trace of this galvanometer is appreciably wider than that of galvanometer (a) and the edges are blurred. The test pattern for galvanometer (c) reveals that either the focus is beyond the range of adjustment or the optics have excessive aberrations. In either event lens replacement is necessary. A subsequent test film made with slightly less exposure showed this particular unit to have optimum focus adjustment. The trace of this galvanometer is quite wide and has very poor edge definition.

As may be seen in Fig. 5, the device is capable of diagnosing whether the galvanometer optics are unacceptable because of optical aberrations or focus maladjustment. Moreover, if the need for focus adjustment is revealed, the direction and amount of adjustment required are indicated.

Figure 6 shows the "twin" instruments now in use; one by the galvanometer manufacturer and one by the customer. Test records from these machines are identical and serve as a "common denominator" regarding product quality.

Although this apparatus was developed for a specific purpose, it is conceivable that the techniques employed might be exploited in similar equipment for the quality testing of photographic optics.

Reference

A somewhat similar apparatus, the Wetthauer "tilted plate test instrument for lenses," is described in *Zeitschrift für Instrumentenkunde, 41:* 148 (1921).

PHOTOGRAPHIC SCIENCE AND ENGINEERING
Volume 3, Number 2, March-April 1959

A Low-Intensity Ultraviolet Sensitometer

R. F. NEWELL, *Film Testing Division, Eastman Kodak Company, Rochester, N.Y.*

A sensitometer has been built to simulate exposure conditions that prevail in the commercial use of the ultraviolet sensitive film and plate products used in photographic spectrometry. A low-pressure mercury-vapor germicidal lamp is used as the radiant-energy source. In order to prolong the exposure to approximate spectrograph exposure times, the radiation is directed at a diffuse reflector. A portion of the energy is redirected to the film. The radiation is modulated by a sector wheel rotating close to the film to produce 15 steps of 0.15 log E increments on the film. Tests indicate that results with this sensitometer correlate well with those obtained with the spectrographs on which the films are exposed by the user.

In the sensitometric testing of the photographic films and plates used by spectrographers, exposures in the ultraviolet portion of the spectrum are necessary because that region is of chief importance in the normal use of such sensitized materials. Intensity-scale exposures of durations equivalent to those in a spectrograph are also required to avoid difficulties arising from reciprocity failure in the photographic materials under test. The requirements may be met by the use of a spectrograph itself as a sensitometer, in a manner similar to that used by the spectrographer in spectrochemical analysis.[1] This is not practical, however, for testing in relatively large volume. An intensity-scale sensitometer with an ultraviolet source of low intensity is therefore what is needed in the sensitometric testing of spectrum analysis materials. The design and construction of such a sensitometer is the subject of this report.

The Special Requirements

There were three basic objectives in the design of the ultraviolet sensitometer:

1. To obtain an ultraviolet source of radiant energy of sufficiently low intensity, or to suitably attenuate the emission from a source of higher intensity, to allow its use in a compact instrument.
2. To provide a precise method of obtaining an exposure time of about 20 sec.
3. To modulate the illuminance on the test sample through a logarithmic range of about 2.3 in discreet adjacent steps of 0.15 in log illuminance. The step width (distance from one step to the next) must be 1 cm., and the area of each step must be at least 1 sq cm.

Experience with a 4-watt mercury germicidal lamp proved it highly acceptable as an ultraviolet source for the present purpose. The lamp emits 80 to 90% of its radiant energy in the wavelengths below 2800 A and the major part of this is concentrated in the mercury line at 2537 A. This type of emission is very suitable for the exposing of spectrographic films. Although this is the practical source of lowest intensity with the required quality of ultraviolet radiation available to us, it is too powerful for the long exposure time specified. When used directly with an exposure time of 20 sec, this lamp must be placed at least 30 ft from the film to avoid overexposure.

The use of the 4-watt source in an instrument of reasonable dimensions requires attenuation by a factor of approximately 100. This presents a problem because

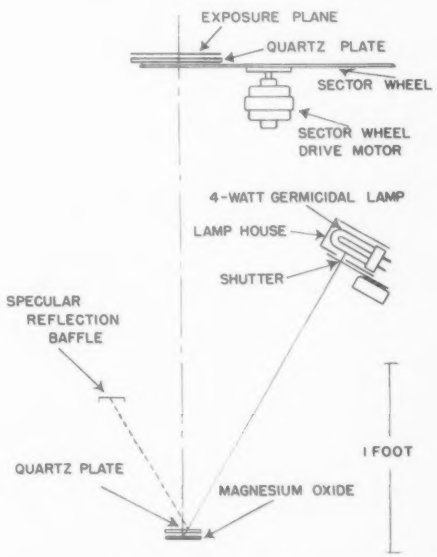


Fig. 1. Low-intensity ultraviolet sensitometer (schematic).

Presented at the Annual Conference, Rochester, N.Y., 8 October 1958. Received 12 September 1958.

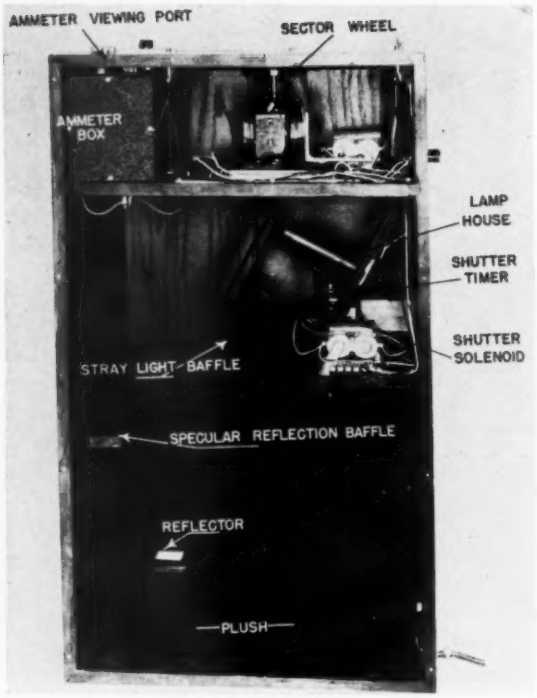


Fig. 2. Low-intensity ultraviolet sensitometer (interior view).

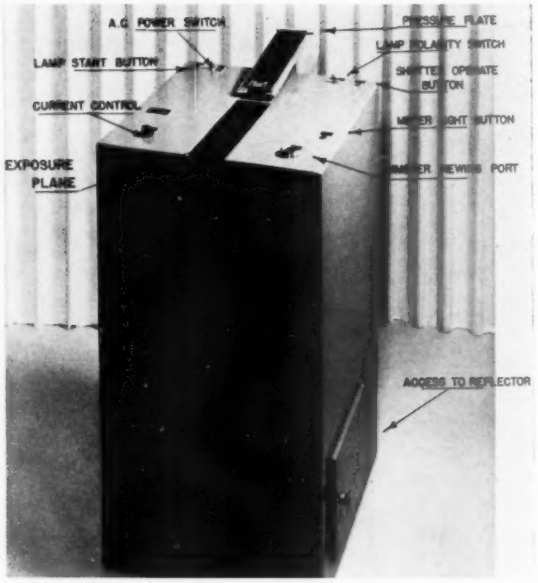


Fig. 3. Low-intensity ultraviolet sensitometer (front view).

no neutral stable absorber is available with sufficient transmittance at 2537 A to obtain the required attenuation by control of the concentration or optical thickness of the absorbing material, nor is a ready means at hand for the spectrophotometric measurement in that spectral region. There are, however, diffuse reflecting materials of good neutrality down to the far ultraviolet, and the desired attenuation may be obtained by reflecting the lamp beam from the surface of such a material. This expedient is employed in the present design; the material chosen for the diffuse neutral reflector is magnesium oxide.

The exposure interval is controlled by a flag shutter operated by a rotary solenoid which is connected electrically to an industrial timer. The main component of the timer is a synchronous electric clock.

The exposure modulation is accomplished in a manner similar to that used by the spectrographer, i.e., by a rapidly rotating stepped sector wheel or disk. The stepped sector disk in the sensitometer is much larger in diameter than in the spectrograph because of its much larger step size. In the sensitometer, the disk is placed near the film to be exposed, whereas in the spectrograph it is located near the entrance slit. A step tablet cannot be used in the sensitometer, because all the available step tablet materials have too high an absorption in the far ultraviolet. It has been shown[2] that when the speed of rotation of the sector wheel is sufficiently high, the exposure becomes equivalent to a continuous exposure of intensity equal to the average intensity during the intermittent exposure.

The Sensitometer

A schematic drawing showing the essential components of the sensitomter is shown in Fig. 1. The lamp is located 21 in. from a 2-in. sq magnesium oxide patch which in turn is 31 in. from the film. This arrangement results in about a 100 times reduction in exposure level from that for the lamp located in the position occupied by the magnesium oxide patch.

The lamp is enclosed in a cylindrical lamp house with an opening in the front. The lamp house opening is normally closed by a shutter operated by a rotary solenoid. The solenoid is controlled by a timer to open the shutter for 20 sec.

The magnesium oxide patch is protected from dirt and abrasion by a quartz plate. The specular reflection from the quartz plate is trapped by a baffle to limit stray light.

The double-cut sector wheel is 16 in. in diameter and has 14 radial steps in increments of $\sqrt{2}$ in angular opening cut in the disk, providing 14 steps of 0.15 log exposure increments. A fifteenth step is exposed outside the periphery of the sector wheel. The sector wheel is driven at 1700 rpm which corresponds to the speed used by the spectrographer. A quartz plate is located between the film and the sector wheel to prevent foreign objects or fingers from getting into the spinning sector wheel.

The interior of the sensitometer is pictured in Fig. 2. Baffles and light-absorbing plush material are used to keep stray light to a minimum. The lamp current is measured with a milliammeter. The milliammeter is

enclosed in a box which may be illuminated on the inside. A viewing lens and safelight filter are combined in the port on the top of the sensitometer through which the meter is viewed. The operator is thus able to view the meter and set the proper lamp current with a minimum of extraneous light entering the room. The board mounting the sector wheel motor and the ammeter box has an opening to permit the radiation from the magnesium oxide patch to reach the film.

The exterior of the sensitometer and its operating controls are shown in Fig. 3. Two 35mm by 12-in. films are exposed side by side. The density steps on the processed film are 1 cm in length so that the densities can be measured on our automatic densitometers.

The sensitometer is not calibrated on any absolute energy scale, but provides a fixed relative log-exposure value which may be used to compare ultraviolet-sensitive materials.

Discussion

When the sensitometer was put into operation, a series of tests were conducted to compare sensitometric results between a 3-meter grating spectrograph, a doubly-dispersing ultraviolet monochromator in the Kodak Research Laboratories, and the new sensitometer. The tests were made using several emulsions of different speeds. All of the test methods agreed as to the relative speeds of the emulsions.

The instrument does not provide a complete ultraviolet test on spectrographic emulsions since its radiation is largely at a single wavelength. Testing to determine the characteristics of many wavelengths throughout the spectrum is probably best done using a spectrograph, although this is not practical for a large volume of work. Comparisons were made with the sensitometer described and the 3-meter grating spectrograph to determine if there is any difference due to size of the exposed area. It was found that with the slit widths normally used and the emulsions tested, there is no noticeable difference.

Conclusion

The new sensitometer provides good sensitometric correlation with practical methods used in spectrographic exposure. The exposing and automatic density measurement made possible by the new sensitometer results in improved and more uniform large-volume testing of the ultraviolet films and plates produced for spectrographic work.

References

1. Harrison, G. R., Lord, R. C., and Loofbourow, J. R., *Practical Spectroscopy*, Prentice-Hall, Inc., New York, 1948, Chap. 13.
2. Webb, J. H., *J. Opt. Soc. Am.* 23: 316 (1933).

PHOTOGRAPHIC SCIENCE AND ENGINEERING
Volume 3, Number 2, March-April 1959

Photographic Exposure Guides and Meters

E. P. WIGHTMAN, *Research Associate, George Eastman House, Rochester, N. Y.*

Part III—Actinometers

Efforts to measure thermal as well as chemical intensity of solar light were made as far back as the 17th century. Originally, actinometry was applied mainly in chemistry, physics, astronomy, and meteorology. Until the 1860's, both thermal power and actinic power of solar radiation were measured principally by scientists, and, even until 1859, largely for other purposes than photography. Thermal power of solar radiation was measured with the differential thermometer, actinic power principally by the action of light on gases and on solutions of solid substances dissolved in water. Use of light-sensitive silver-halide paper to measure the intensity of actinic light began with Landrini in 1818, according to Eder. Numerous sensitized-paper actinometers were produced for specific purposes prior to 1885, when W. F. Stanley devised the first popular actinometer for photography. At that time, gelatin-silver-halide-emulsion dry plates were coming into general use. After Stanley's actinometer appeared, several actinometric exposure meter-calculators were patented and marketed. The early investigators, the later successful inventions, and the comparative merits of sensitized-paper actinometers and other types of actinometers are described and discussed.

1. Introduction

"The measurement of the intensity of a ray of light," said William Crookes,[1a,b] in 1868, "is a problem the solution of which has been repeatedly attempted, but with less satisfactory results than the endeavours to measure the other radiant forces. The problem is susceptible to two divisions — the absolute, and the relative measure of light. . . ."

"(1) [The intensity of a beam of light may be expressed] by some absolute term," he continued, "having reference to a standard, or standards, capable of accurate reproduction at any time and place by any reasonably capable person.

"(2) The standard may be purely a relative one with which the unknown intensity of light is compared at each operation."

Actinometers are devices which measure, with a greater or less degree of certainty, the chemical or actinic power of light — the origin and discussion of the definition of the name will be given later. Some meters can be considered as absolute, although many of these are far from that; others are strictly relative.

Actinometers which have been used in photography* may be divided into two general types: (1) those which make use of light-sensitive gaseous reaction, gas destruction, or gas formation — these might be called *chemical actinometers* — and (2) those which use mainly a light-sensitive silver salt on paper. There are also *differential thermometers*, which are physical rather than chemical in their operation and measure heat, or heat produced by absorption of other radiation. They operate by absorption rather than by chemical change.

Actinometers were originally designed for scientific study or application, but with the advent of photography they were quickly adopted for estimating exposure.

It should be noted that not all the ingredients of white light are chemically active. Only those in the blue, indigo, violet, and ultraviolet end of the spectrum act to any appreciable extent on ordinary (nonorthochromatic and nonpanchromatic) photographic plates and films and usually on actinometers designed to measure actinic light. This was demonstrated by William Crookes in 1853,[1c] as well as earlier by Sir Humphry Davy in 1812, and by Becquerel in 1839, as we shall see in the next section.

2. Early Chemical Actinometers

The earliest forms of actinometers were used simply as light meters many years before photography began. Even in the early days of photography actinometers were not used specifically as exposure meters, but were employed merely to measure the relative actinic value of light. The actinic value then had to be converted to useful data for exposure tables or calculators. The earliest actinometers, as well as some later ones, were

Received 5 August 1958.

* It should be noted that several important systems currently used in photochemistry depend on the production or destruction of color. For example, the modern potassium ferrioxalate actinometer, which is both rapid and easy to use, utilizes the very sensitive color reaction between orthophenanthroline and the photochemically formed ferrous ions, instead of carbon dioxide production or oxalate disappearance, thus achieving a thousand-fold increase in sensitivity.

based principally on chemical reactions involving gases, or solutions of solids which, in light, produce gases. In some cases gases were formed and the amounts were measured; in others, gases reacted, being transformed into liquid, or being changed into a different gas which dissolved in a liquid. The loss in volume could then be measured. The gain or loss in volume — or the loss in weight, where the gases formed were allowed to escape — provided means for determining the amount of light action, and hence, the actinic intensity of the light, the lapsed time being known.

Extensive researches have been carried out on light-sensitive chemical reactions. Light-sensitive gases, gaseous mixtures, and solutions of substances in liquids which produce a steady, measurable chemical reaction during exposure to light, but which are unreactive in the dark, have all been studied. For examples, there are: mixtures of chlorine and hydrogen, hydriodic acid, carbon monoxide and oxygen, among the gases; oxalic acid solution, ferric oxalate solution, and a solution of the latter containing gold chloride, among the reactive solutions; and many other gases, gas mixtures, and solutions.

Some of these photosensitive reactions have been used in actinometers for measuring light intensity. From the data obtained, special tables have been prepared, as will be seen later, for use in photography.

The French chemist Count Claude Louis de Berthollet discovered, in 1785, that chlorine water solution liberates oxygen gas when exposed to light. But he did not utilize this fact to measure the intensity of the light action. J. M. Eder states, in his *History of Photography*,[2a] that the Swiss physicist Horace Bénédict de Saussure published, in 1790, his experiments on measurements of the sun's rays at high altitudes using chlorine water.[3] Saussure, according to Eder, noted that the rate of development of the quantity of gas is proportional to the intensity of the light, and proposed the construction of a so-called *photometer** based on this reaction. This, we believe, with Eder, was the first *chemical actinometer*, although it was not given that name. Eder says that Saussure deserves the title "father of chemical light measurement."

The word *actinometer* was apparently first used by Sir John F. W. Herschel in the *Report of the Third Meeting of the British Association for the Advancement of Science, Cambridge, 1833*.[4a] There it is stated, in an article entitled "Explanation of the Principle and Construction of the Actinometer": "This is an instrument, invented by Sir John F. W. Herschel, for measuring at any instant the direct heating power of the solar rays. . . .the actinometer is intended to afford a dynamical measure of the solar radiation, i.e., one in which the actual quantity of heat received per second, or in a given infinitely small time, is the object of measurement, upon a given surface directly exposed to the sun."

*The word *photometer* was frequently very loosely used in those early days to mean any device for measuring the intensity of light — chemical and silver-salt actinometers, differential thermometers, and visual photometers.

The *Oxford English Dictionary*,[5a] under the word *actinometer*, attributes the origin of the device (not of the word) to Sir John F. W. Herschel, in 1825, and cites the *Edinburgh Journal of Science*, for that year.† However, no article by Herschel containing any mention or description of such a device is to be found in the two volumes for 1825. But in a letter by William Ritchie, A. M., Rector of the Academy of Tain, dated May 20, 1825,[8] addressed to Dr. David Brewster, Editor of the *Journal* in question, Ritchie states: "A simple and ingenious method has lately been proposed by J. F. W. Herschel, Esq., Sec. R. S. Lond., which promises complete success [in measuring and comparing] the calorific effects of the sun's rays in different latitudes, and at different elevations, and at different periods. As I am not aware that this method has yet been printed, I shall take the liberty of quoting his own description from one of his letters." There follows Herschel's description of his device, which was actually a *differential thermometer*, based upon heat absorption from solar light rather than upon the action of *actinic* light. We shall treat this further in Sec. 3.

E. Becquerel, in 1839, experimented on the actinic and electrochemical effect of sunlight, and invented a photoelectrochemical, silver-halide actinometer based on this effect.[9] It was not a silver-halide sensitized-paper actinometer but a silver-halide-coated plate in liquid, with a galvanometer connection. He called his arrangement the *actinomètre electrochemique* and this, we believe, was the first crude photoelectric meter, about which we shall have more to say in a later paper. Here is, to the best of our knowledge, the first use of the word *actinomètre*, the French equivalent of the English word *actinometer*, meaning a device for measuring the chemically active intensity, as distinct from the heating power, of solar light, or more specifically, of that portion of sunlight or other radiation which is absorbed and which produces chemical action in the substances upon which it falls.

The first published definition of the English word *actinometer* (with the above meaning) which we have been able to find, other than the casual one mentioned in Herschel's paper[4a] in 1833, is in a section of *Photographic News*, for Nov. 26, 1858, headed "Dictionary of Photography," and is attributed to Robert Hunt,[7b]

† The *Oxford English Dictionary*[5a] defines the word *actinometer* as: "An instrument for measuring the intensity of the sun's heating rays; first invented by Sir John Herschel and described in the *Edinb.* [*urgh*] *Journal of Science*, for 1825." Even the latest edition of *Webster's New International Dictionary*[6a] gives as two definitions: "a. An instrument for measuring the direct heating power of the sun's rays. b. An instrument for measuring the actinic power of a light source, usually by means of a light-sensitive paper giving a progressively darkening spot; specif. *Photog.*, a form of this instrument for measuring the exposure to be given in printing." Of course, the use of the instrument need not be confined to determining print exposure, but could be, and was, extensively used as well for obtaining negative exposure.

Although the *Oxford English Dictionary*[5a] defines the actinometer as a *thermal* instrument, it defines *actinism*[5b] as: "That property in the sun's rays by which chemical changes are produced, as in photography," but to compound the incongruousness, it quotes Robert Hunt's paper[7a] on "Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants" (p. 30). The *Dictionary* defines *actnic* as: "Of or pertaining to actinism."[5c]

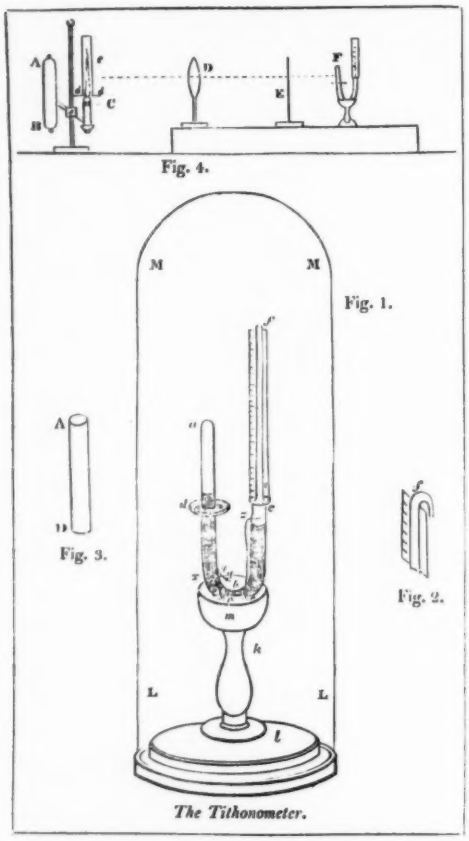


Fig. 1. Diagram of John W. Draper's *Tithonometer*. [From description by Draper in the *Philosophical Magazine*, December 1843.[11a]]

an English mineralogist and outstanding photographic scientist, and one of the founders of the Royal Photographic Society. The definition given is: "An instrument for determining the variations of actinic power [of solar radiation]." *Actinic* is defined as: "of or pertaining to actinism." *Actinism* is the term which the above *Dictionary* states[7b,c] was given by Hunt: "to that principle of the solar spectrum which produces the phenomenon of chemical change."[7b] Hunt in his book *Photography: A Treatise on the Chemical Changes Produced by Solar Radiation*. . . .,[7e,d] further defined the term *actinism* by saying "it signifies nothing more than ray-power," and continuing, "it is now very generally adopted," which implies that the idea must have been proposed some time prior to 1852 when the book was first published.

As we shall see in Sec. 4, Sir John Herschel used the term *actinograph* for the device he first employed for measuring solar radiation intensity. This device was of the silver-halide-paper-recording type. Herschel's *actinometer*, as already mentioned, was a differential thermometer, quite different from the *actinograph*.

We return now to Becquerel. He measured the spectral intensities of light of different wavelengths by means of his photoelectrochemical apparatus. He found that the different colored radiations composing white light differed from one another in their actinic action on silver chloride. This had previously been noted by Sir Humphry Davy,[10a] and credited by him to M. Ritter and Dr. Wollaston.

The first invention and use, of which we are aware, of a gas-reaction actinometer employed in photography — it was used as well for other purposes — was the instrument (Fig. 1) devised by Professor John W. Draper, M.D., of New York University. He called it a *tithonometer*, and described and discussed it in detail in December 1843.[11a] Draper dipped into classical mythology to name the instrument — from Tithonus, mortal spouse of Aurora, goddess of the dawn. In another legend, Tithonus was originally a sun god. Draper's device, like the man in the first legend after whom it was named, never attained immortality. It was soon forgotten.

Draper stated that: "The great desideratum in the science [of optics] is a photometer [i.e., actinometer] which can mark down effects by movements over a graduated scale. . . .The tithonometer consists essentially of a mixture of equal measures of chlorine and hydrogen gases. . . . This mixture is kept in a graduated tube so arranged that the gaseous surface exposed to the rays never varies in extent, notwithstanding the contraction which may be going on in its volume, and that the muriatic acid resulting from its union is removed by rapid absorption."

In 1857,[11b] Draper reviewed his earlier work, and mentioned other forms of the tithonometer, notably the modified form used by Robert Bunsen and Henry Enfield Roscoe in their extensive photochemical researches, to be dealt with below. He also discussed the use of an aqueous solution of peroxalate of iron, which may be kept indefinitely in total darkness without change, but which decomposes to give carbon dioxide gas and a precipitate of the protoxalate of iron when exposed to actinic light. He states that "the ray which chiefly affects it is indigo, the same as that which affects the tithonometer, and the silver compounds used in photography. This ray, to produce its effect, undergoes absorption, as may easily be proved by causing a sunbeam to pass through two parallel strata of peroxalate, when it will be found that the light which has gone through the first portion is inoperative on the second. . . .

"In the application of peroxalate of iron to photometry [i.e., actinometry]," says Draper, "several different methods may be followed. The course I have most commonly taken has been to determine the quantity of carbonic acid gas produced — sometimes by volume, sometimes by weight. It is of course understood, that before any carbonic acid gas can be disengaged, the solution must become itself saturated therewith; and that before we can correctly measure the quantity of light by the quantity of acid produced, this dissolved portion must be ascertained. . . .

"On this principle I commenced an attempt to determine the hourly and diurnal illumination of a given

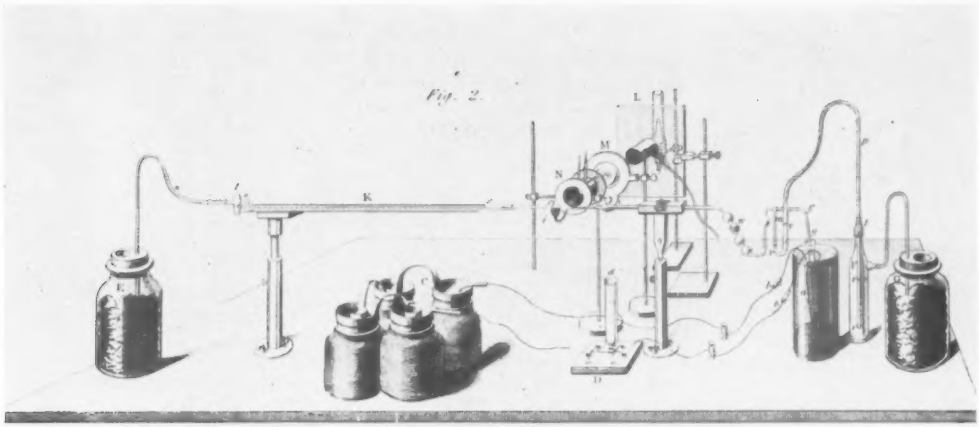


Fig. 2. Diagram of Bunsen and Roscoe's chlorine-hydrogen *actinometer* (not so named by them).
[From the *Philosophical Transactions of the Royal Society*, 1857.[17a]]

locality. . . .Among the important results which may be expected from these new modes of photometry, and which will doubtless be furnished at an early period, are the hourly, diurnal, and annual quantities of sunlight."

In connection with the use of peroxalate of iron in an actinometer for determining the diurnal amount of light, the Englishman John C. Draper (not to be confused with the American, John W. Draper, cited above), in August 1859,[12] suggested the addition of perchloride of gold to the iron compound solution. When light acts, a precipitate is formed, and its weight gives a measure of the amount of light action. Certainly, with such an equipment the light's intensity cannot be measured rapidly.*

Harry N. Draper (still another Draper), also in England, in September of the same year, described[13] a simple actinometer using peroxalate of iron. He determined the loss in weight with the loss of carbon dioxide resulting from light action.

In 1855, W. C. Wittwer[14] indicated that the action of sunlight on chlorine water followed the principle† said by many subsequent writers to have been enunciated in 1867 by C. M. Gulberg and P. Waage as the Law of Mass Action.‡[15] Wittwer, too, constructed and used a chlorine-water actinometer. Eder is probably correct, however, in giving priority for such a meter to Saussure.

Between 1857 and 1863, Robert William Bunsen, of Heidelberg, Germany, and Henry Enfield Roscoe, an Englishman of Manchester, published a series of papers with the general title, "Photochemical Researches."[17,28a] In their first paper they described a chlorine and hydrogen-gas actinometer (Fig. 2) which, as we have said above, was a considerable improvement on Draper's tithonometer, being much more accurate.

They discussed comparative and absolute measurements of chemical (actinic) rays, and employed burning carbon monoxide as the standard light source for determining the absolute measurements. This standard flame was that produced by the free combustion in atmospheric air of carbon monoxide under rigid, specified conditions.

They defined "the photometric unit [of luminous intensity] for the chemically active rays to be that amount of action which is produced in one minute by a standard flame placed at a distance of one meter; and we determine experimentally for each instrument the number of such units (n) which correspond to one division on the observation tube [of the actinometer]. By multiplying the observed number of divisions (t) by the number of photometric units (n), equal to one division [$t \times n$], the observations are reduced to a comparable standard whose unit is taken to be the amount of action which a standard flame at a distance of one meter effects on the normal mixture of chlorine and hydrogen in one minute when the depth of insolated gas is so small that the alteration of the value of the coefficient of absorption for different sources of light becomes inappreciable.

"*We call this unit a chemical unit of light, and ten*

* There are, however, faster modern actinometers used in photochemical researches; for example, the system employing potassium ferrioxalate solution and orthophenanthroline, which, with light action, yields ferrous ion and carbon dioxide.

† Wittwer stated that for constant light intensity $-\frac{dC}{dt} = KC$, C being the chlorine concentration and K a constant (from Plotnikov's *Photochemie*[14b]). If Wittwer had used a different reactant, however, he might have obtained a different result. The proportionality between rate and concentration depends upon the relatively weak absorption of light by the chlorine. Reactions are known where the absorption is strong and the rate is essentially independent of concentration.

‡ There is even some question about Gulberg and Waage's priority in this matter. E. A. Guggenheim,[16] of the University of Reading, England, credits A. Horstmann (*Ann. Chem. and Pharm., 170:* 192 (1873); *Verhand. Naturhist-Med. Ver. Heidelberg*, (5) *1:* 465 (1877): Ostwald's *Klassiker*. . ., Nr. 137) as having first established the law quantitatively. He sums up by saying "to Gulberg and Waage belongs the credit of being the first to appreciate qualitatively the nature of balanced reaction. But they did not succeed in correctly formulating a quantitative expression for the equilibrium condition until six years after Horstmann had done so. . . ."

thousand of these units, one chemical degree of light." [Italics theirs.]

Bunsen and Roscoe measured with considerable exactitude the intensity of sunlight and of total daylight at different hours of the day, in different months of the year, and at different latitudes. Most of their work was done with their chlorine-hydrogen actinometer. The data they obtained were far more accurate and quantitative than similar types of data gathered by any previous investigators.*

As one would suspect, the data showed that actinic intensity of solar radiation increases to a maximum during the day and then decreases, and this was shown to be related to increase and decline in altitude of the sun. Intensity increases during the first months of the year, reaching a maximum in June, and then decreases. Of course, for this comparison, the intensity during the same hour each day was used. Also, there is a change with change in latitude. The intensity increases as one approaches the equator. Direct sunlight intensity varies at a different rate and amount, however, as compared with skylight.

Bunsen and Roscoe's earlier work anticipated Hurter and Driffield's efforts along the same line by twenty-odd years, but its main purpose was largely photochemical rather than photographic. However, it and the somewhat later investigations of Roscoe alone, and of Roscoe and Thorpe, which will be discussed in Sec. 4, formed the basis of photographic light intensity and exposure tables for many years thereafter.

C. J. Burnett, in December 1858,[19a] mentioned the tithonometer of Draper but apparently was ignorant of the work of Bunsen and Roscoe. He suggested a self-registering apparatus for determining the actinic intensity of daylight throughout the day. His actinometer had much the same form as the Bunsen and Roscoe apparatus; however, he proposed the use of peroxalate of iron instead of chlorine and hydrogen as the light-sensitive agent. This, too, was not new, since it had already been proposed by Professor John W. Draper. Even the self-registering feature was not new, as we shall see later. Burnett suggested the use of a roll of sensitized silver-halide paper for the recording, the paper passing behind a measuring tube and a narrow slit in a metal plate. The length of the mercury column, which was in a horizontal position, as in the Bunsen-Roscoe apparatus, would thus be recorded at each instant of the day on the sensitive paper as it was moved past the slit at right angles to the mercury column. Some modifications of this original instrument were described by Burnett in July 1860.[19a,b]

A little over a year later Thomas Woods published a paper — "Description of a New Actinometer"[20] — in which he also suggested the use of peroxalate of iron. Burnett commented on this paper, pointing out that Wood's suggestion was not new,[19b] and reviewed other actinometers which he himself had devised.[19b–d]

In the middle sixties and later, quite a number of individuals became interested in the carbon process, the invention of which is generally attributed to Sir Joseph W. Swan, in 1864. The principle on which it was based, however, was discovered by Fox Talbot in 1852. By this process, an image of pigment mixed with chromated gelatin is produced. When exposed to light under a negative, the chromated gelatin is hardened by light action and the unexposed areas can be washed away in warm water. From the beginning, the problem arose as to how much exposure to give. At first, exposure was determined by trial and error. Later, special actinometers were invented for determining correct exposure. Most of these were of the sensitized-paper type and will be discussed in Sec. 3.

Carey Lea, however, in 1867[21] suggested for the carbon process a liquid-gas actinometer, utilizing a strong solution of ferric oxalate and ammonia. Exposure of the ammonium ferric-oxalate solution to actinic light causes it to give off carbon dioxide gas, which changes the level of the liquid in the attached capillary tube. This suggested apparatus is very similar to the previously mentioned peroxalate of iron actinometers of Draper, Burnett, et al. Moreover, it was not the first actinometer invented for use in the carbon process, as we shall see presently. We mention it only because of its suggested use of ammonium ferric oxalate.

Another chlorine-hydrogen actinometer was described by H. Dufour, in *Photographic News* in April 1881.[22] It was based on a counterbalancing of the light-induced combination of hydrogen and chlorine by an electrolysis of hydrochloric acid solution. When the rate of evolution of hydrogen and chlorine in the electrolysis balanced the rate of the photochemical combination, the intensity of the light could be determined by measuring the current density necessary to produce this steady state.

The earliest patent application on an actinometer of the gaseous-reaction type appears to have been made in England by a Frenchman, J. E. Dessendier,[23] in November 1866. The patent was granted a year later. Essentially, the device consisted of a regulator allowing continuous exposure to light of a mixture of chlorine and hydrogen. These gases, as we have said, do not react with each other in the dark at room temperature, but when exposed to light they combine in proportion to the light's intensity. Loss in volume due to dissolving of the hydrochloric acid is measured.

As late as Aug. 3, 1893, after silver-halide actinometer exposure meters were becoming popular, J. Kremer, of M. Gladbach, Germany, was granted a British patent[24] on an actinometer in which hydrochloric acid solution was first electrolyzed in the apparatus to give hydrogen and chlorine, which combine again when exposed to light. Here again loss in volume is measured.

Chemical actinometers were never popular. They were developed in a period when photographers were largely rugged individualists with regard to their equipment, supplies, and methods of operation, and who didn't have produced for them devices suitable for the masses.

* Yet there were serious critics of their system; e.g., John Sebelien, who, in 1898, read a paper before the Chemical Association of Christiania, in which he mentioned errors due to absorption of ultraviolet radiation by the glass and to the exothermic character of the reaction.[18]

3. Differential Thermometers

A report of "Decisions on Disputed Inventions and Discoveries" was published early in 1825 in the *Edinburgh Journal of Science*. It stated that Sir Humphry Davy, in his *Elements of Chemical Philosophy*,[10b] credited the alchemist Van Helmont (1577–1644) of Brussels with having invented a differential thermometer, described in Van Helmont's *Opera Omnia*, for measuring minute changes in the heat content of solar radiation, and other slight heat changes. Davy thus disputed the priority of Sir John Leslie to the invention of the differential thermometer.

Sometime in 1804, or a little before, Professor Sir John L. Leslie, Scottish mathematician and physicist, announced the invention of a differential thermometer and described it in his book, *Experimental Inquiry into the Nature and Properties of Heat*, published in 1804.* Eder,[2b] referring to Leslie's device, quotes from a book by Meissner as follows: "In Meissner's *Handbuch der allgemeinen und technischen Chemie* (1820), II, p. 280, *Chemie der nichmetallischen Stoffe*, Abteilung A, mention is made of the application of light. Meissner writes: 'The property of light which causes different color substances to become decomposed under development of heat furnishes us with a means of measuring the intensity of light. On this is based the arrangement of the photometer invented by Sir John L. Leslie (1766–1832) in 1804. It consists of two thermometers of equal size, the bulb of one having been blackened.' " Here there seems to be some confusion because Meissner appeared to have considered Leslie's device as one for measuring chemically active rays, when he spoke of decomposition, whereas Leslie used a thermal means of measurement.

On Feb. 2, 1804, Count Rumford also announced[25] at a meeting of the Royal Society the construction of an instrument which he called a *Thermoscope;* it was intended for use as a differential thermometer. Count Rumford was loudly charged by Leslie not only with having stolen his invention, but even with having abstracted, or caused to be abstracted, certain sheets of Leslie's work from the printing office. We have not attempted to follow this imbroglio to learn how it was finally settled, since it is not of sufficient importance here. The important fact is that neither Leslie nor Rumford was the true inventor of the differential thermometer, there being two earlier candidates for the honor.

Davy showed[10b] that the differential thermometer claimed to have been invented by Professor Leslie was anticipated more than a century and a half before by Johan Baptiste Van Helmont. Davy compared the diagrams of the devices and found that they were essentially alike (see Fig. 3).

The *Edinburgh Journal* report stated: "Although no candid inquirer could doubt that Van Helmont anticipated the invention of the differential thermometer, yet there was one little loophole in his description of it through which a person of small dimensions might creep; and in this way, from a slight flaw in the indictment, the differential thermometer has been allowed to preserve a kind of separate existence."

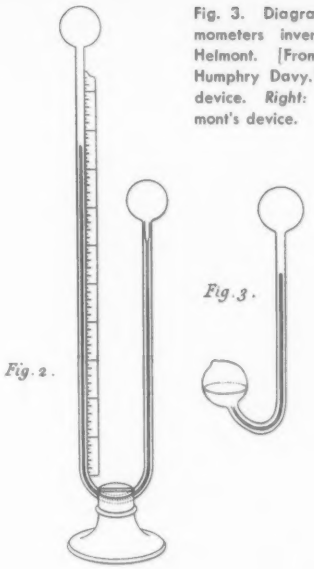


Fig. 3. Diagrams of the differential thermometers invented by Leslie and Van Helmont. [From the *Collected Works* of Sir Humphry Davy.[10b]] *Left:* Sir John Leslie's device. *Right:* Johan Baptiste Van Helmont's device.

The report then abandoned the cause of Van Helmont and went on to state: "We are now prepared to *prove* that the differential thermometer was invented by John Christopher Sturmis, Professor of Mathematics at Altdorff, who published an accurate account of its construction and theory, illustrated by drawings, in his *Collegium Experimentale Curiosum*, which he published in Nuremberg, in 1676." He called his device a *thermometer* and also a *thermoscope*, the latter the very name used by Count Rumford many years later. The description of it, in Latin, is quoted, without translation, in the report. Apparently Professor Leslie's and Count Rumford's differential thermometers were similar to it, and all were somewhat similar to that of Van Helmont. It is quite possible that each produced his invention without knowledge of the work of the others. Such things have happened.

Essentially, Sturmis's device consisted of a glass capillary U-tube containing a colored liquid, connected to two glass bulbs filled with air. One of the bulbs was made of black glass or porcelain, and the other of thin, colorless, transparent glass. When solar light fell on these, the heat (and light too, for that matter, if light was present, which is converted to heat by absorption) was absorbed by the black bulb, but that which fell on the other bulb very largely passed through unabsorbed. The black ball transferred its absorbed heat (or heat produced when light is absorbed) to the air inside, and this air expanded, producing a difference in level of the colored liquid, which difference was measured on a scale.

We omit further discussion of the history of the

*We have not been able to locate a copy of this book, but the researches reported in it won Leslie the Rumford Medal of the Royal Society of London.

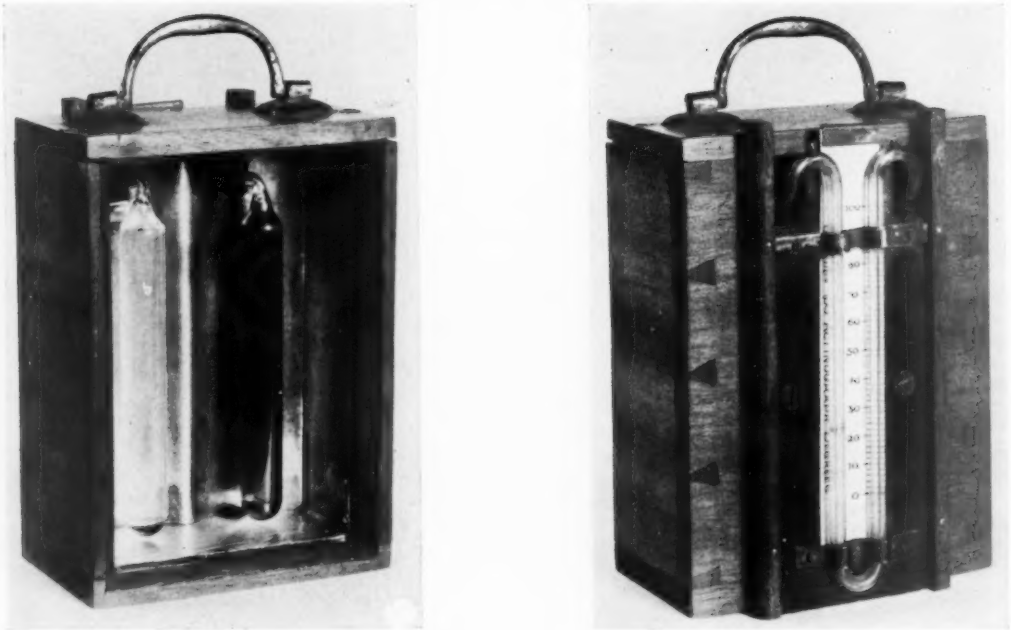


Fig. 4. Ferdinand Hurter's "*Actinometer.*"[26a] [Photographs courtesy of George Eastman House, from an *Actinometer* in its collection] *Left:* The differential thermometer bulbs. *Right:* The measuring U-tube and differential scale.

differential thermometer between 1676 and the time when Hurter and Driffield appeared on the scene.

On April 23, 1881, Ferdinand Hurter applied for a British patent on *Photometers and Actinometers*, and received it on Oct. 19, 1881.[26a] While the device covered by this patent, a differential thermometer similar in principle to those previously described, does not fall strictly in the actinometer class, since no chemical action is involved, it is considered here because of its importance in the development of photographic science in its early stages.

The two bulbs of Hurter's differential thermometer (Fig. 4), although tubular instead of spherical, are attached to a capillary U-tube as in the previous devices. One of them is made of ruby glass, or is coated with a red material, and absorbs rays of various wavelengths. The other bulb is transparent, uncoated glass, or is coated with white, and very little light is absorbed by it. One arm of the U-tube is connected to the ruby-glass bulb, the other arm to the colorless transparent bulb, and some colored liquid is placed in the lower half of the U-tube. The bulbs are sealed. A copper mirror is placed behind the bulbs, and a suitable, movable, differential scale, with a zero mark on one side and a scale of arbitrary degrees on the other, is placed behind the U-tube.

In the dark or under ruby light, uniform temperature change of the bulbs does not affect the level of the liquid in the U-tube, but diffuse daylight or other light on the bulbs causes a change in level because of expansion of the air in the ruby bulb due to heat absorption. The difference in level is measured by bringing the zero mark to the top of the liquid in the tube on one side and reading the number of arbitrary degrees from 0° level to the top of the liquid on the other side. The number of arbitrary degrees indicated is proportional to the intensity of the light.

Walter Clark states, in his article *Actinometry, Sensitometry, and Density Measurement*,[27] that "for many years Hurter and Driffield themselves made all their photographic exposures by the aid of this instrument, but it was unsuitable as a marketable commodity." It provided, however, the light tables for the H & D *Actinograph* (described in Part II of this series[28a]). In a paper in the *Journal of the Society of Chemical Industry*,[26b] later reprinted in the *Hurter and Driffield Memorial Volume*,[29] Hurter reported a series of observations made with the Actinometer every day of the year 1885–86. As might be expected, intensity of daylight goes up in the first part of the year, to a maximum in June, and down to a minimum by the end of the year. This is in agreement with Bunsen and Roscoe's,[17a–e] with Roscoe and Thorpe's,[49a–e] with C. Wood's,[30] and with others' findings, obtained by different procedures.

Some other types of differential thermometers were described in 1908 by W. A. Michelson in the *Physikalische Zeitschrift*.[31] In the first of these a platinized plate was used in one side of the instrument. In the second type, a bimetallic device with a platinum-copper sandwich was used. In a third, a platinum-aluminum combination was employed. Michelson marketed a device of his own through an agent, Schmidt & Haensch, in Berlin.

4. Silver-Halide and Other Standard-Tint Actinometers

We come now to actinometers which used some type of sensitized paper, usually a silver-halide paper, and, as a rule, a standard tint or series of tints. The first devices of this kind were not photographic exposure meters but, like the early chemical actinometers, and, as we plan to set forth in a later article, like the early photometers also, were instruments used in other fields, such as meteorology, physics, and photochemical investigations.

A convincing account of what Joseph Maria Eder[2b] stated was the earliest silver-halide standard-tint actinometer of which we find an account was that said to have been designed by Count Marsiglio Landrini of Vienna, Lord Chamberlain to Archduke Albert of Saxony-Dresden. Eder states that at some time not later than 1818, Landrini constructed an automatic self-recording "photometer," which used silver-chloride paper — known at the time through the works of Thomas Wedgwood and Sir Humphry Davy, and later, in 1832, through the application of silver-salt paper by Georg Scheutz[2c, 32a] to the making of maps, as stated in his *Handbok i Lautmäteriet*.

Eder[2b] quotes Meissner as follows: "'Landrini proposed another photometer (different from Leslie's differential thermometer device) based on the decomposition of horn silver (silver chloride) by light, which consists of a round disk coated with chloride of silver, covered by another opaque disk which is pierced. It is covered in such a manner that the second disk is turned a little by clockwork every half hour, which exposes at each turn a new portion of the lower disk to the action of light. In sunlight, different portions undergo in this manner an unequal darkening by which the difference in intensity of the light at different hours of the day can be measured.'

"This is," Eder continues, "the first description of a self-recording daylight photometer [i.e., actinometer] using light-sensitive silver-chloride paper and Meissner evidently learned it directly from Landrini not later than 1818 [the year Landrini died]; the first publicity about it was given by Meissner in 1820."

According to Robert Hunt,[7e] the first published account he could find of an instrument for automatic recording photographically, and for measuring the actinic power of light with sensitized paper, was an article, "On a Mode of Registering the Indications of Meteorological Instruments," in the *Sixth Annual Report of the Royal Cornwall Polytechnic Society, 1838*.[33a] The article was by Thomas B. Jordan, an engineer and inventor in Falmouth, England.

The publication, although dated 1838, contains a report of the sixth annual meeting of the Royal Cornwall Polytechnic Society, held Thursday, Jan. 24, 1839, in Falmouth. The report is followed by several articles, of which Jordan's is one. His article begins:

"The principle of self registration is so obviously advantageous for all instruments used in meteorology, that I imagine it is only requisite to show its possibility, in order to claim the attention of every admirer of the science [of meteorology]. The plan* which I adopt for this purpose, is to furnish each instrument with one or more cylinders, containing scrolls of the photographic paper, prepared according to the directions of H. F. Talbot, Esq. [From another context it appears that Talbot and Jordan were good friends.] These cylinders are made to revolve slowly by a very simple connection with a clock, so as to give the paper a progressive movement behind the index [and a slot in the outer cylinder] of the instrument, the place of which is registered by the representation of its own shadow. . . .the division between the light and dark parts of the paper shows the height of the mercury, and the fluctuations in the intensity [lightness and darkness] of the shade, represent corresponding fluctuations in the intensity of the light shining on the instrument, so that in fact it answers the double purpose, of marking the height of the barometric column and noting the time of every passing cloud. This fact has given rise to the contrivance of a new Instrument, which it is proposed to call a Heliograph†; its object is to yield an accurate account of the intensity of the light for every minute of the day, and permanently to register its indications. . . ." Jordan continues: "The Heliograph may be differently constructed, according to the views of the observer, either to show the intensity of the sun's light throughout the day, as already described, or to show the amount of light transmitted from each quarter of the atmosphere. Mr. Fox has suggested to me a valuable modification of it for this purpose." Jordan does not say how the image on the paper was fixed, although evidently it must have been.

His *Heliograph*, so far as we know, is the next earliest self-recording, photographic-paper actinometer, after that of Landrini. Figure 5 is a simplified diagram of the instrument.

In the Seventh Annual Report of the Royal Cornwall Polytechnic Society, 1839,[33b] Jordan published

---

* Jordan's asterisk. Jordan's footnote says: "This plan was first named to a committee of the Society, held on the 18th of February; and at a subsequent meeting, on the 21st of March, a paper on the subject was read, and some of the photographic registers were exhibited."

Note that the day and month are given, but not the year. This probably was 1839, and the actual date of publication of the *Sixth Annual Report* was *after* the papers of Jordan and other authors had been presented to the Cornwall Society in March 1839. We are unable at present to verify this, yet it would be of great interest to be sure of this date, since Jordan's use of the word *photographic* could involve a priority as to its first use. This matter will be considered in a paper to be published elsewhere. Hunt, in his book *A Popular Treatise*. . . ., published in 1841[7e] seems to confirm the 1839 date.

† Here is another word that has been loosely used. Nicéphore Niepce, in 1829, used the word *heliograph* for his process of producing pictures on glass, and later for his gravures on copper.[7f, 34] So here are two meanings. There are five meanings of the word given in the latest edition of *Webster's New International Dictionary*,[6b] which says: "1. *Photog.* a. A. photoengraving. b. A photograph. c. An instrument for taking photographs of the sun: a photoheliograph. 2. An apparatus for measuring the intensity of sunlight. 3. An apparatus for telegraphing by means of the sun's rays thrown from a mirror. . . ." Jordan used the word still differently. Had he defined it, he might have said, "an instrument for determining the actinic intensity of solar radiation."

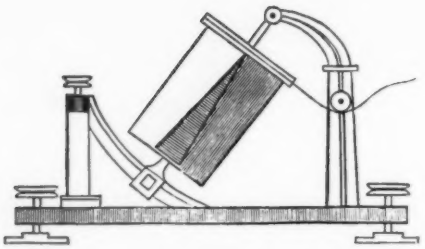


Fig. 5. Diagram of Thomas B. Jordan's *Heliograph*, an instrument for self-recording the intensity of actinic, or chemically active, light during 24 hours of the day.[33a, b] [From *A Popular Treatise on the Art of Photography including Daguerreotype*, by Robert Hunt, Glasgow, 1841.[7e]]

another paper, "Description of a New Arrangement of the Heliograph for Registering the Intensity of Solar Light." In it he presented a detailed plan for giving numerical values to the indications of light intensity by the instrument. This apparatus and method made it possible to compare data from distant stations for the same day and hour.

It should be noted that Jordan's description of his first actinometric device appeared (if the 1839 date is correct) five months prior to the full description of Daguerre's process by Arago, and that he used a sensitized paper rather than an iodized silver plate. The application of the photographic procedure was, however, to a field other than photography.

Faustino Jovita Malaguti,* an Italian by birth, used, in early 1839, the darkening of silver chloride as a measure of the intensity of light.[35] According to Eder,[2d] Malaguti "accepted in 1839 the hypothetical law of blackening [of silver halide] in which $i \cdot t$ = constant [the *Reciprocity Law*]," where i = intensity of light, and t = time of exposure, but Malaguti did not give sufficient proof to establish it. In reading through his articles we have been unable to find any suggestion of this reciprocity principle, although he did devise a matching standard for determining the effect of certain colored liquids on the light sensitivity of silver-chloride paper by interposing the colored liquids between the sensitized paper and the light beam; he also devised a form of sensitized-paper actinometer.† He noted, too, that the intensity of sunlight varies with the obliquity of the sun's rays.

When the daguerreotype process was published in France, in August 1839, no directions were given by Daguerre for judging exposure, but M. Hubert,[28a] in France in the following November, and D. W. Seager, in the United States in 1840,[28a] had presented crude exposure tables in connection with Daguerre's manual. Exposure was largely a trial-and-error procedure. ". . .parce que rien n'est visible," said Daguerre,[3ra] "et qu'il est de toute impossibilité de determiner le temps necessaire à la reproduction, puisqu'il depend entierement de l'intensité de lumière des objets que l'on veut reproduire; ce temps pent varier pour Paris de 3 à 30 minutes au plus." Those who tried to estimate the exposure found it not so easy. Some kind of meter would have been of great assistance.

It was stated by Dr. Helmer Bäckstrom, of Stockholm, Sweden,[32b] that the unknown translator of Daguerre's manual into Swedish, in 1839,[37b]‡ was the first to suggest that a silver halide be used for a photographic actinometer. In a footnote in the Swedish edition (pp. 16–17), the translator suggested that the photographic plate holder be so made that part of the plate should remain outside the holder when the plate was in place in the camera. By gauging the exterior part in steps of exposure, the course of the exposure inside the camera could be gauged, either visually or by chemical treatment.[37b] That the unknown translator's suggestion did not get wide recognition is no doubt due to its being in Swedish rather than in French or English.

Obviously, from what we have already said, Bäckstrom is in error as to the priority of the unknown translator's suggestion of an actinometer, although the type suggested was unique. Landrini,[2b] Jordan,[33a] Malaguti,[35] and even Arago[36] evidently anticipated the Swedish translator in the general idea of using silver halide to measure light intensity, Landrini and Jordan in actual practice, although these two did not

* Not "Malagutti," as Eder spelled it.

† Bunsen and Roscoe later also referred to Malaguti's reciprocity assumption without citing a reference to it.[17e] They stated that Hankel ("Messungen über die Absorption der chemischen Strahlen des Sonnenlichts," *Abhandl. d. Kon. Sachs. Gesellschaft Wissenschaften, 1862*, Bd. IX, p. 55) [This is a reference which we have not been able to confirm.] verified Malaguti's assumption within the slight variation of intensity from 1 to 1½ light units.

It was not until 1863, when Bunsen and Roscoe published the results of their research *On Direct Measurements of Chemical Action of Sunlight*,[17e] that the Reciprocity Law was finally established over a moderately wide range of light intensities and times, and that actinometry based on this and their earlier work was placed on a scientific basis. They produced a silver-halide actinometer, and an excellent standard gray for use in actinometry and sensitometry—one part of pine soot, 1000 parts of zinc white, and some gelatin. They called the instrument they used a *pendulum photometer*.

It is interesting to note in this connection that Dominique Francois Arago,[36] in his presentation of Daguerre's process to the Chambre des Députés, on July 3, 1839, hinted, perhaps without realizing it, at a kind of reciprocity principle when he said [our translation]: ". . .by its aid [i.e., by the aid of photography] the natural philosopher may in the future proceed to absolute intensities [of light]. He will compare lights by their effects. If he deem it useful, he may obtain with equal facility a print of the dazzling rays of the sun, of those, three hundred times weaker, of the moon, and of the rays of stars. These plates will be made in equal intensity, either by weakening the strongest light, by an excellent method [which he did not mention, but which was probably by some kind of filter], or by letting the most powerful rays act during a second only, for instance, and letting the others last half an hour."

It should also be noted that Arago's statement contains, in addition, the hint — indeed the first hint, so far as we know, in connection with photography — of a photometric-actinometric means of determining the relative intensities of light from two or more different sources, using silver-halide paper for the purpose.

‡ A copy of this book, published by Adolph Bonnier in Stockholm just before Christmas 1839, is in the archives of the George Eastman House, Inc., Rochester, N.Y. We are greatly indebted to the late Brigadier General O. N. Solbert, Director of the George Eastman House, for translating for us passages of this book.

apply their ideas to photography; Arago merely suggested his ideas.

On February 20, 1840, Sir John F. W. Herschel read a paper[4b] before the Royal Society, London, on an *Actinograph, or Self-Registering Photometer for Meteorological Purposes*. This "photometer" was actually a silver-salt-paper *actinometer* to which Herschel gave the name *Actinograph*.* This, we believe, was the first use of the word "Actinograph" for an actinometer device. The instrument was operated by clockwork, but was too clumsy and expensive, and so unsuitable for use by the average, or even the advanced, photographer, of those early, or even later days. It was intended only for scientific use, mainly in meteorology and astronomy.

J. B. Soleil, a French optician, published a paper on May 25, 1840, in the *Comptes rendus hebdomadaires des Séances de l'Académie des Sciences*,[38,39] in which he gave an account of a primitive actinometer, without specifying a standard gray scale. Erich Stenger claimed that Soleil's was the first attempt to produce a chemical (silver-halide) exposure meter (actinometer),[39] but this, too, is obviously incorrect.

Stenger recorded[39] that not long after Soleil's paper was published, K. Lewandowsky, of Vienna, in 1843, described his *Bejodungs- und Belichtungsmesser für die Daguerreotypie*,[40] an exposure meter-sensitometer device which allowed exposures to be made by steps at 10-second intervals on a daguerreotype plate also made in steps. Thus the best choice of iodizing and exposure could be determined, there being 36 to 70 varying steps from which to choose. The sensitometric exposure device is said to have been marketed by Prokesch, in Vienna. It was apparently the first crude sensitometer that was actually produced and sold.

One other reference of interest given by Stenger[39] is to a silver-chloride "photometer" independently described by Dr. Heeren, in 1844.[41] Dr. Heeren is said to have used in this actinometer a hand-made standard tint.

In the November 1848 *Philosophical Magazine*,[42a] Antoine François Jean Claudet,[42, 43, 44] a Frenchman who spent much of his adult life in England, and who was Daguerre's first licensee there, deplored the lack of suitable, accurate means for determining the actinic value of light, which, he noted, is not the same as the visual intensity. Claudet said: "Many ingenious contrivances have been resorted to for indicating the intensity of chemical or actinic rays existing at a given moment; but as the object was to study more particularly the variations of the direct solar rays, it was found necessary to have recourse to complicated instruments furnished with heliostats and clockwork movements."[42a] Claudet reviewed the works of Jordan[33] and Herschel.[4b] He realized that the mere measurement of the strength of the light is only of value in photography if it is correlated in some way with the sensitivity of the photographic material.

"All these several ingenious contrivances," says Claudet, "had no other object than that of measuring the photogenic intensity of the direct rays of the sun during the different hours of the day. Besides, they were applicable only to photography on paper; and the results were uncertain, because the paper does not long preserve the same degree of sensitiveness; then the heliostats and clockwork movements rendered the apparatus complicated, expensive, and difficult to use."

Claudet perfected an instrument (Fig. 6) which he believed overcame these difficulties and provided conditions necessary to render it useful, since it measured simultaneously the actinic intensity of the light (an actinometer) and the sensitiveness of the photographic material (a sensitometer). He called it a *photographometer*. It was intended for use with daguerreotype plates as well as with photographic paper.

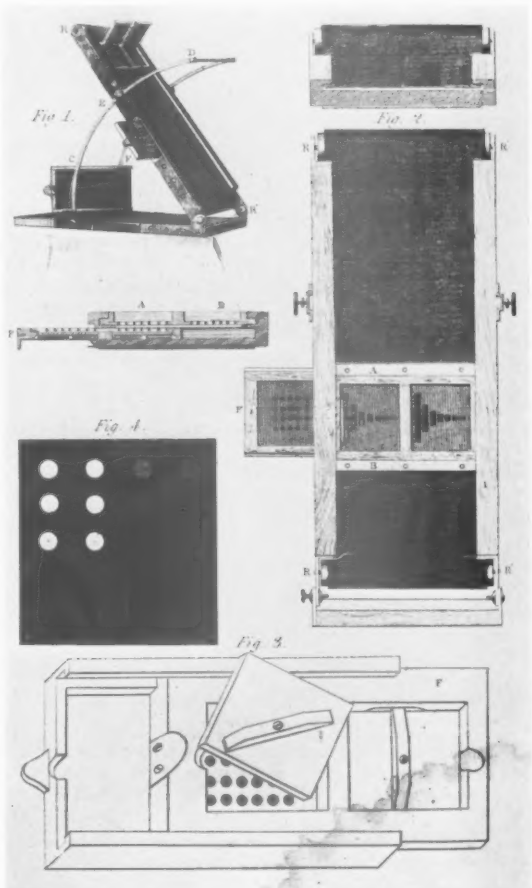


Fig. 6. Claudet's *Photographometer*, a sensitometer-actinometer.[42–44]
[From the *Philosophical Magazine*, November 1848.[42a]]

* Thus we see that the word *actinograph*, in the meaning we give it today, was proposed and used long before Hurter and Driffield's time. As we shall also see presently (p. 74), Hunt used the same word a few years later for an actinographic device. However, this word, and also the words *photometer* (footnote, p. 65), and *heliograph* (footnote, p. 71), as we have seen, were employed very loosely in the early days of photography.

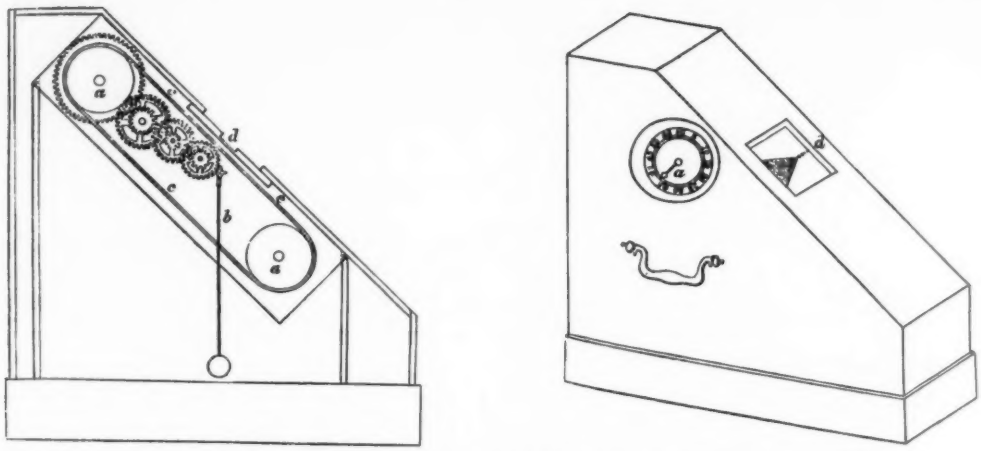


Fig. 7. Robert Hunt's *Actinograph*. [From the *Journal of the Photographic Society*, July 21, 1853.[7h]]
Left: Cross-sectional elevation showing inner workings of the instrument. *Right:* Diagram of the instrument.

Robert Hunt, in 1853, reviewed some of the actinometers invented by others prior to that time.[7h] He stated that before 1853 he had developed an actinometer (Fig. 7) which he claimed was not nearly so complicated and difficult to handle as earlier ones. It was similar, however, to the Jordan device, although somewhat simpler. He called it an *Actinograph*—Ferdinand Hurter and his *Actinograph*[26b] had not yet been heard of, but Herschel had used the word in 1840, as we have said.[4b] Light-sensitive paper was placed like an endless belt on rollers, one of which had a clock mechanism attached. The paper was moved at a given uniform rate behind a triangular slot, as in the Jordan instrument; light passed through the slot, producing a graded exposure on part of the paper. The width of the image which resulted at any point on the paper of given sensitivity showed the relative actinic intensity of the light acting.

Dr. Percy,[45] after commenting on Hunt's paper[7h] when it was presented at the Photographic Society, stated that he himself had made a simple actinometer by placing some chloride of silver in a glass tube, introducing some chlorine, and sealing the tube. He claimed that, when exposed to light, the silver chloride darkened a given amount in a specified time for a certain intensity of light. Longer or shorter exposure was necessary for other intensities. The darkening disappeared in the dark (a reversible reaction).

On page 487 of *Cosmos* for 1853,[46] there appeared a news item alluding to a letter written by M. Schall, of Berlin, to the *Athenaeum* (London), telling of his experiments in using sensitized paper to record variations of light intensity.

In the following year, M.-A. Gaudin described[47] the preparation of sensitized paper and discussed the actinic effect of light on the paper at different hours of the day in different latitudes, but he gave no data.

Nine years later, M. Malval described[48] an actinometer which used silver-chloride paper and a standard tint for comparison.

We come now to an important series of papers by Henry Enfield Roscoe, and by Roscoe and T. E. Thorpe, ranging over the years from 1865 to 1874.[49] In the first of these papers (1865),[49a] Roscoe described the preparation and use of standard fixed strips of light-sensitive paper and a simple exposure apparatus which was calibrated by means of Bunsen and Roscoe's previously mentioned *pendulum "photometer."*[17e] He discussed the accuracy and trustworthiness of the method, and its application to actual registration (recording). Measurements of daylight actinic intensity were made at Manchester and Dingwell, England, and Heidelberg, Germany.

In the second paper,[49b] Roscoe presented observations which were made at Kew, England, by himself, and at Pará, Brazil (1867), by his assistant T. E. Thorpe. As late as this, Roscoe made the statement: "Our knowledge concerning the distribution of the chemically active rays on the earth's surface is as yet very limited, and any conclusions with respect to the intensity of the chemical rays in the tropics have been, up to the present time, based upon the vague and unsatisfactory statements of photographers." He states that according to photographers (Golding Bird, *Natural Philosophy*, 5th Ed. p. 622; Robert Hunt, *Researches on Light*, p. 366[7g]) more exposure is required in the tropics than in London. Thorpe's observations show that light intensities at Pará were considerably greater than similar observations made on the same day of the month and year in Kew. This apparent discrepancy could, in the light of our present knowledge, be explained on the grounds that the photographers were not measuring solar intensity but were photographing tropical scenes in which the important shadows are much denser than they are in the latitude of Kew, and in order to get detail in them, more exposure had to be given.

In the third paper, by Roscoe and Thorpe (1870),[49c] observations were made "On the Relation Between the Sun's Altitude and the Chemical Intensity of Total

Daylight in a Cloudless Sky." It was shown that the mean chemical intensity decreases with decreasing altitude of the sun. The decrease is greater and at a different rate for direct sunlight than for diffuse light. It was also found that the relation between the sun's altitude and the chemical intensity at any given place is represented by the equation:

$$CI_a = CI_0 + \text{constant} \times a$$

where CI_a signifies the chemical intensity at any altitude, a, in circular measure, CI_0 the chemical intensity at 0°, and a is a numerical constant derived from the observations.

The fourth paper[49d] dealt with the measurements of actinic light intensity during a total eclipse of the sun at Catania, Italy.

The fifth and final paper (1874)[49e] described "A Self-Recording Method of Measuring the Intensity of the Chemical Action of Total Daylight." With this recorder less personal attention was required than when each observation had to be made individually. Figure 8 shows diagrams of the recorder.

By means of a properly arranged clock, the sensitive paper, drawn from a spool on which it is wound, is automatically exposed each hour of the day so that in the evening the observer has only to read off in the ordinary way the hourly intensities which were recorded (Fig. 8). Owing (1) to the great variations in the intensity of total daylight at different times of the day and different periods of the year, and (2) to the fact that in order to estimate accurately the chemical intensity, the coloration acquired by the paper must reach, but not exceed, a given tint, it is necessary to make preliminary exposures for a series of known but varying intervals of time quickly succeeding each other. This is done by use of a wheel, operated by clockwork, the wheel having around its circumference a series of metal pegs for making electrical contacts for increasing lengths of time as the wheel turns. The successive times for one particular place and time were 2, 3, 4, 5, 7, 10, 12, 17, 20, and 30 seconds. For places where intensity of light is much greater or much less, other sets of intervals are required. From the preliminary tests the instrument is calibrated and then is ready for use. The method of preparing long strips of sensitized paper of constant sensitivity was also described.

According to a *British Journal of Photography* editorial, commenting on Roscoe's work[50]: "On Friday last [Aug. 21, 1874] in the Chemical Section of the British Association, Professor Roscoe exhibited a photometer [i.e., an actinometer-sensitometer] which possessed several advantages over those hitherto in use." This device, they said, consisted essentially of a step wedge of densities in each of which was printed, in numerical order, a large black number. When sensitized paper was exposed for a given time behind this wedge, there resulted a print showing steps of density in reverse of the original step wedge, including the numerals. The intensity of light could be gauged by the number of steps showing in which the numerals were visible. This was a kind of "extinction" actinometer in reverse. It was evidently not the self-recording instrument above described, but a simpler device, somewhat similar to the carbon-process actinometers; however, it was intended for more general use in photography as well as for other purposes such as meteorology when only individual determinations of intensity were required.

We noted above (p. 68) that after the invention of the carbon process, the workers in this field had difficulty in determining exposures, and we mentioned Carey Lea's photochemical liquid-gas actinometer.[21] In 1866, a year before Lea's suggestion, Sir Joseph Swan invented the first actinometer designed especially for the carbon process.[51]

Quoting Sir Joseph: "It consisted essentially of a piece of sensitive photographic paper [dichromated-gelatin, not silver-salt, paper], a semi-opaque screen covering a portion of the paper, and a simple mechanical arrangement for rapidly allowing the examination

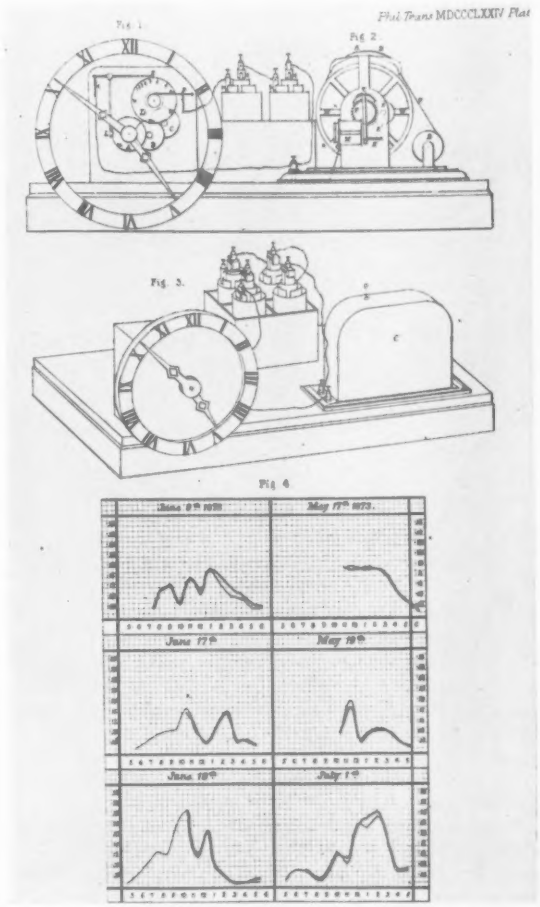


Fig. 8. Henry Enfield Roscoe's self-recording *actinometer* and records of actinic intensity of sunlight at Manchester, England, for certain days in May, June, and July 1873. [From the *Philosophical Transactions of the Royal Society*, 1874.[49e]]

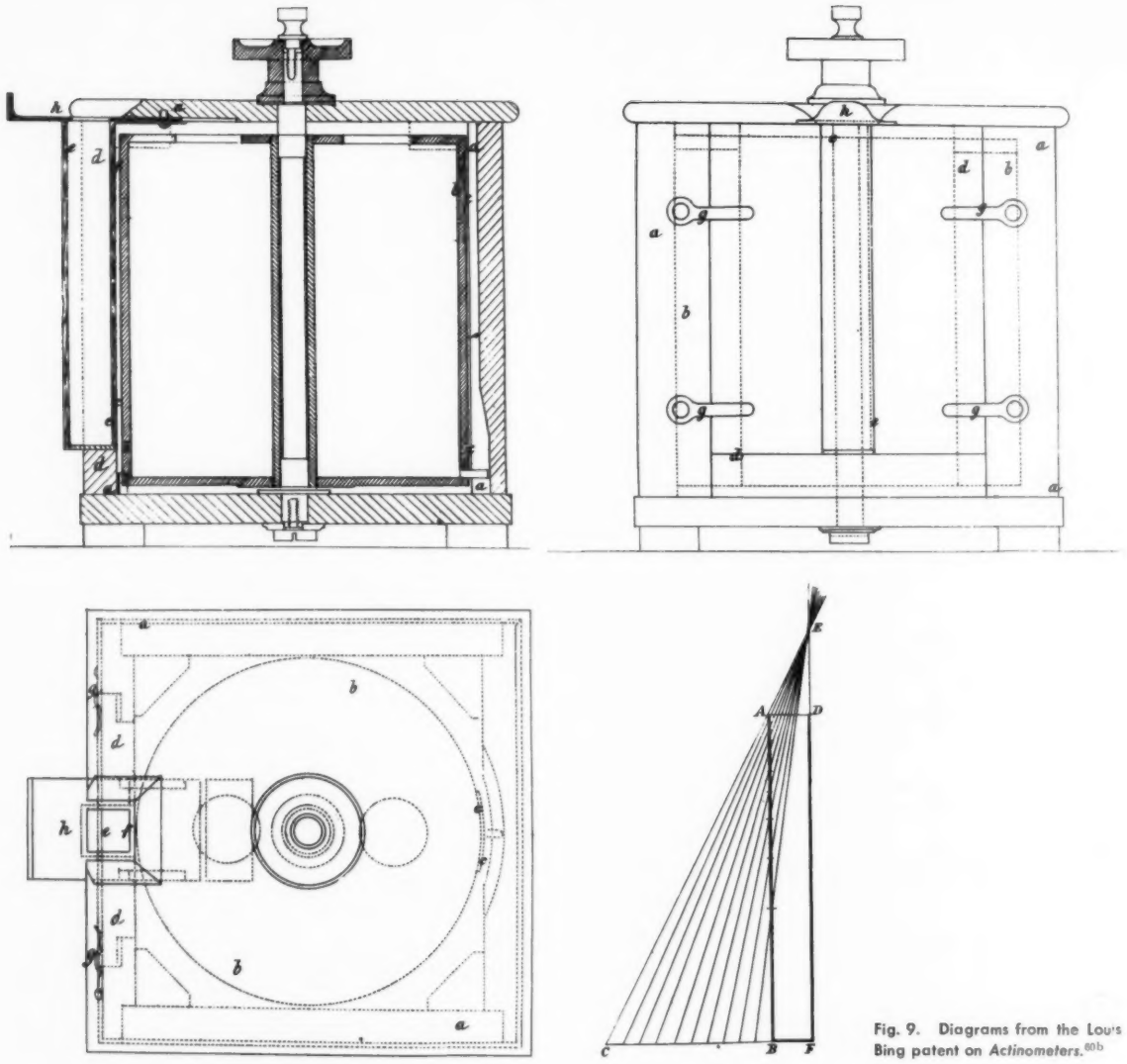


Fig. 9. Diagrams from the Louis Bing patent on *Actinometers*.[60b]

of the process of the light's action on that portion of the paper exposed under the screen, and for bringing a fresh portion of the paper into position when commencing a new operation. . . .The depth of the tint to which the sensitive paper must be printed in order to indicate the proper amount of exposure for a particular negative, or class of negatives, has to be ascertained by preliminary experiments. When the tint is once ascertained, it is matched with one of the ten tints in the scale, the number of the tint being noted on the negative; it is afterwards easy to print with uniform results by simply observing the tint of the paper in the actinometer, [and applying the exposure required to produce that tint].

"The actinometer screen is formed of a slip of glass coated with a collodion film, and darkened by sensitizing and developing in the usual manner to a degree of translucency corresponding to the darkest printing portion of the negatives."

Among others who have contributed to the subject of carbon-printing actinometers and to the process itself are H. Vogel;[52a, b] the Editor of the *British Journal of Photography*, who described, in one of his editorials, a Spencer actinometer,[53a] and commented on it and the process, and the H. B. Burton actinometer[53b]; additional contributors were J. R. Johnson[54]; W. E. Debenham[55]; and a few others.[56–59] Some of the later devices were considerable improvements on the earlier ones.

The first silver-halide actinometer for which a patent was requested was, we believe, that of Louis

Bing.* On Sept. 13, 1866, he applied for a British patent,[60a] which provided him with "provisional protection only," but the patent was not granted. On April 21, 1868, however, Bing applied for a somewhat similar patent for *An Improved Mode of and Apparatus for Ascertaining the Actinic Power of Light*, and this time it was granted[60b,c,61] (Fig. 9).

Quoting from the patent: "I provide a surface on which the light shall fall in such a manner as to produce a graduated series of shades ranging from full light to any desired degree of obscurity, and for identifying the shades thus provided, I apply thereto a graduated figure scale. To the surface thus lighted I apply a sheet or strip of sensitive or photogenic standard paper, and obtain thereon by exposure for a determined time a graduated representation of the progressive change of tone from light to darkness. [Here, again, was a kind of actinometric extinction meter.]

"The instrument. . .may be constructed in various forms. Thus it may consist of a single tube or a series of tubes of various lengths, or [may have] the form of a parabola, ellipse, etc."

In the *British Journal of Photography*, and also in *Photographic News*, both for May 26, 1876,[62a,b] Captain W. de W. Abney described the Roscoe self-recording actinometer,[49e] and pointed out some of the difficulties in the system. He himself constructed a similar but smaller, simpler instrument, in which he placed over the sensitized paper a box with a narrow slit in the top. Over the slit was placed a graduated density scale obtained photographically. The paper was on a cylindrical drum which was revolved once every 24 hours by clock mechanism. The step-wedge-exposed image was compared with four standard tints.

W. E. Batho had described a somewhat similar device[63] in the previous year. Batho's instrument was a clock-like actinometer which produced a concentric wedge-density on sensitized paper. Densities on the wedge were compared with a standard set of tints, and the distance along the wedge from the starting point to the point of matching gauged the intensity.

Abney, in another article, "On Actinometers,"[62c] in the *British Journal Photographic Almanac for 1876*, pointed out that "It had been usual in constructing actinometers [of the silver-halide paper type] to take one of two principles—either to produce a tint in open light corresponding to a painted tint, and, therefore not variable; or to use different thicknesses of some actinic-light-absorbing material, noting where the figure painted over some particular number of thicknesses is just apparent." "The latter method," said Abney, "is accurate, as a certain number of tints produced must mean that the sensitive silver paper received a certain quantity of actinic light. The former method is uncertain — much more so than generally believed — and the actinometer should be distrusted except for rough approximations." Yet, as we shall see, many popular actinometers which depended on a single standard tint were later put on the market.

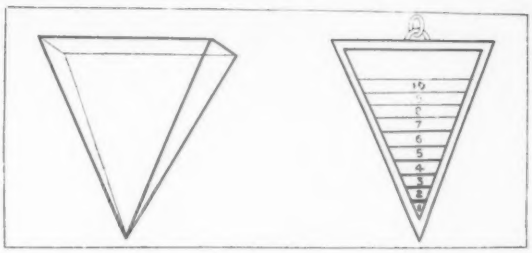


Fig. 10. M. Hemagis's prismatic-type actinometer, called the *Photomètre à Prisme*. It was made of yellow glass, and was said to be unaffected by heat and moisture. [From the *British Journal of Photography*, Dec. 17, 1875.[64]]

M. Hemagis,[64] in late 1875, invented a simple little prismatic device which could be used as a watch fob (Fig. 10). He said it was a "corellaire" to his tourist camera and called it a *Photomètre à Prisme*.

The *Photomètre à Prisme* was nothing more than a nonbreakable step-density wedge. A piece of sensitized paper is introduced under the prism and is allowed to be acted on for one minute by the direct or reflected light whose intensity it is desired to determine. From the number of steps printed on the sensitized paper, either the light intensity or the exposure for a given sensitive material, or both, can be derived.

The *British Journal of Photography* for Dec. 7, 1877, carried a brief article, signed "C.P.,"[65] in which an actinometer for landscape work was described. The design was based on the principle that it is the light *reflected* from the objects being photographed which tints the actinometer paper rather than the direct light from the source being used. A tapering hood of light cardboard was made to fit loosely on the small tin actinometer, manufactured, it was said, by the Autotype Company. The hood was so constructed that it had the same angle of view as that of the camera lens. The inside of the hood was blackend to prevent internal reflections. So far as we are aware, this is the first reflected-light actinometer to have been put on the market for photographic use, although, judging by lack of further mention of it in the literature, it did not become popular.

Walter Clark, in his review of exposure meters,[27] stated that: "Some of the earliest exposure meters of this [silver-halide paper] type [what he called Class (a)] were due to Boisan (in 1861), Vidal (in 1862 and 1865), Malval (in 1863), Ritschie (in 1876), and others, but they were not particularly suited for rapidly and accurately determining exposures. The simple instruments are not much used at the present time [1927] except for printing purposes — and in particular for printing carbon tissue. A number of instruments of this type are issued by the Autotype Company — for example, the simple box type of Johnson [Johnson's Autotype Print-Meter, single-tint, especially for carbon printing] and the *Autotype Disc Actinometer*. Another instrument of similar type

* As we said previously (p. 71), Landrini, according to Eder, produced the first silver-halide, standard-tint actinometer, for other than photographic purposes. So far as we know, it was not patented, nor were any of the other earlier sensitized-paper actinometers.

Fig. 11. The *Watkins' Standard Exposure Meter*, first put on the market in 1890, and advertised and sold until some time in 1907, when this model was discontinued — a combined actinometer and calculator.[70a-d] [Photograph courtesy of George Eastman House, from a Watkins meter in its collection.]

was described by Lamy in 1881. These are single-tint instruments. Other instruments were devised having a number of matching tints of different depth of tint (Woodbury; Goldmacher; Autotype Co.)."*

We come now to the period when Hurter and Driffield were actively engaged in their researches, and when the gelatin-silver-halide dry plate was becoming popular. The advent of the dry plate gave a great impetus to the manufacture of small, easily portable and operable actinometers. The more important of these will be considered.

First, however, we mention that in November 1884, Cleveland Green and Louis Varley Füidge applied for a British patent on a meter of the standard multiple-tint type.[66] This meter, as described in the patent, was in the form of a flat box with cover or lid of glass or porcelain, on the under face of which was attached a graduated scale of tints arranged radially, numbered from one upwards, and separated by transparent areas. We do not know if this device ever appeared on the market, but apparently it was the first patented *exposure* meter of this form.

Léon Vidal, in his *Manuel du Touriste Photographie*, in 1885,[67] mentioned a simple density-scale actinometer which he called *Pose-Photomètres négatifs*, but he did not say much about it. This is apparently a later Vidal meter than the one mentioned by Clark.[27]

The first photographic exposure actinometer-calculator to become moderately popular was that of William Ford Stanley in 1886. Stanley, on April 13, 1885, applied for a British patent on an *Actinometer for Photography*.[68a] Apparently this first attempt was abandoned, but on March 31, 1886, he and William Low Sarjeant made application for, and two days later, were granted a patent on a single-tint, box-type actinometer using sensitized silver-bromide paper.[68b] According to the description, it was in Clark's Class (b), i.e., it was an actinometer with separate calculator. Hudson's Photographic Exposure Scale† was recommended as the calculator for use with it.

Stanley, Manufacturer, produced and offered for sale an actinometer based on this patent before the end of 1886.[69a] Advertisements in the *British Journal Photographic Almanac* over a period of years indicate that it remained on the market at least until some time in 1890.[69b] The ads in the *Almanac* ceased after that; however, Eder mentions a Stanley meter which he said appeared on the market in 1892.[2e] Alfred Watkins, who soon afterwards produced a meter under his own name, said in 1890:[70a] "Stanley is at present the only maker who sells such actinometers [referring to a paper by a Mr. Burn, in the *Photographic Society Reporter* for November, 1899, in which Burn advised exposing the sensitized actinometer paper to the 'best light' — clear sunshine at midday in May or June]— but their [its] general principle was a free gift to the public before the patent was taken out. . ."

Although the Stanley actinometer attained a limited popularity, the first actinometer to become highly popular, and to remain so in modified forms over many years, was that of Alfred Watkins. It fell into Clark's Class (c), i.e., it had a calculator incorporated with it, and was quite convenient to use. Watkins' first patent application in England was made on Jan. 27, 1890,[70b] and in the United States on Nov. 20, 1890.[70b]

Watkins described this meter (Fig. 11) in the *British Journal of Photography* in 1890[70a] and told how exposures can be calculated mathematically.

* We have not attempted to find in the photographic literature the patent or other information on most of these meters mentioned by Clark; they were all similar in principle.

† We have seen no other mention of this scale in the literature.

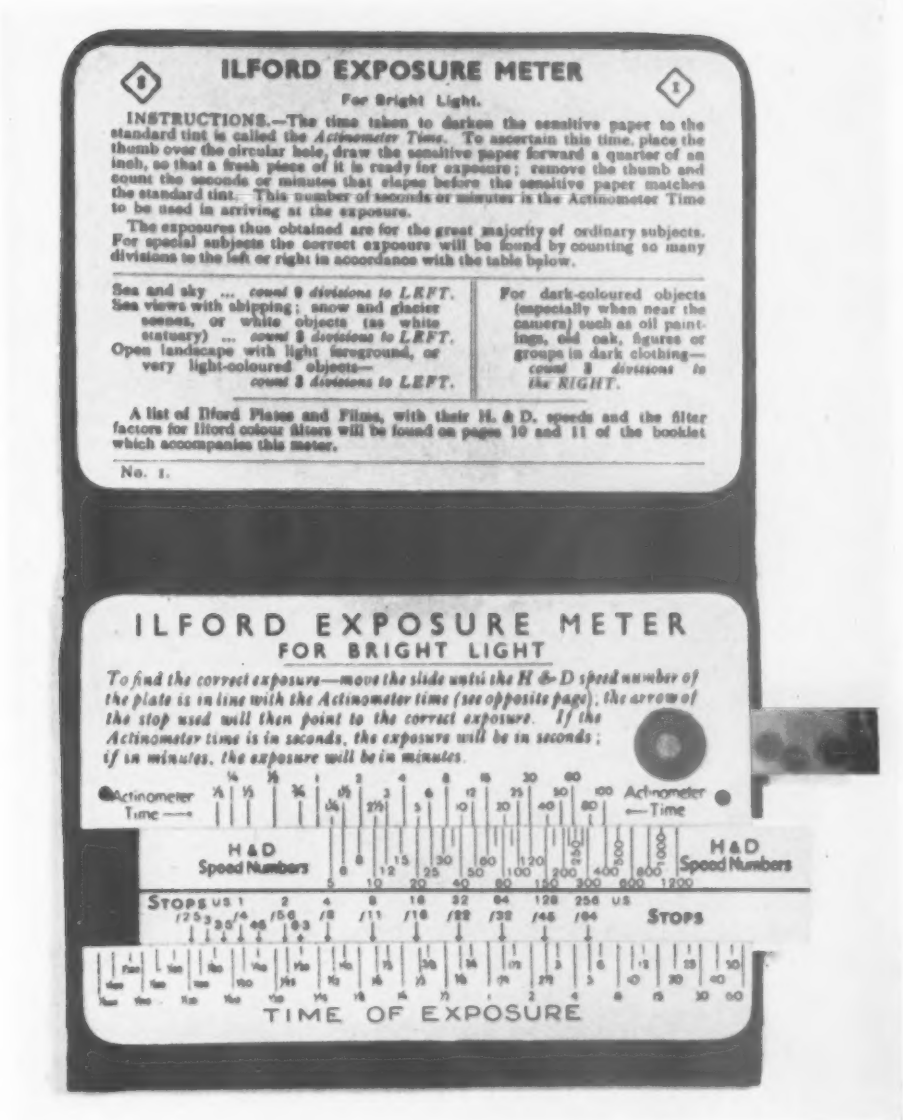

ILFORD EXPOSURE METER
For Bright Light.
INSTRUCTIONS.—The time taken to darken the sensitive paper to the standard tint is called the Actinometer Time. To ascertain this time, place the thumb over the circular hole, draw the sensitive paper forward a quarter of an inch, so that a fresh piece of it is ready for exposure; remove the thumb and count the seconds or minutes that elapse before the sensitive paper matches the standard tint. This number of seconds or minutes is the Actinometer Time to be used in arriving at the exposure.
The exposures thus obtained are for the great majority of ordinary subjects. For special subjects the correct exposure will be found by counting so many divisions to the left or right in accordance with the table below.
Sea and sky ... count 0 divisions to LEFT.
Sea views with shipping; snow and glacier scenes, or white objects (as white statuary) ... count 3 divisions to LEFT.
Open landscape with light foreground, or very light-coloured objects— count 3 divisions to LEFT.
For dark-coloured objects (especially when near the camera) such as oil paintings, old oak, figures or groups in dark clothing— count 3 divisions to the RIGHT.
A list of Ilford Plates and Films, with their H. & D. speeds and the filter factors for Ilford colour filters will be found on pages 10 and 11 of the booklet which accompanies this meter.
No. 1.
ILFORD EXPOSURE METER
FOR BRIGHT LIGHT
To find the correct exposure—move the slide until the H & D speed number of the plate is in line with the Actinometer time (see opposite page); the arrow of the stop used will then point to the correct exposure. If the Actinometer time is in seconds, the exposure will be in seconds; if in minutes, the exposure will be in minutes.
Actinometer Time
Actinometer Time
H&D Speed Numbers
H&D Speed Numbers
STOPS
STOPS
TIME OF EXPOSURE

Fig. 12. One of the *Ilford Exposure Meter-Calculator* booklets open, showing the actinometer and slide-rule calculator.[77] [Photograph courtesy of Percy W. Harris, F.I.B.P., Hon. F.R.P.S., F.P.S.A.]

The early Watkins meters were advertised first by Watkins himself,[70c] at Hereford; and later by W. E. Haines (Wholesale for Alfred Watkins,)[71] also at Hereford; by R. Field & Co.,[72a–c] of Birmingham; and still later by the Watkins Meter Co.[73a–c]

The early cylindrical-type Watkins meter had a chain attaching the cap, or a chain to which was attached a little metal ball. The directions for using the meter stated that the chain and cap, or ball, could serve as a pendulum to count the seconds required to bring the sensitized paper to the standard tint. The actinometer part of the device was on the opposite end from the chain and cap. It contained a roll of sensitized paper and a single standard tint against which to match the exposed spot on the paper. Movable and fixed scales appeared on the cylindrical surface. It should be noted that Watkins' standards of light, exposure apertures, exposure times, and plate speeds, once fixed, were not altered in subsequent meters.

There were many models put on the market over the years, to as late as 1931.[70b–g, 71–74] They had three general forms. The early ones were in tubular or cylindrical form (standard). Others were watch-like (Bee, Queen Bee, and Snipe Meters, for example). Still others were of the multiple-disk

type (Hand-Camera Meter). One of the Bee meters had a special dial for Autochromes. Still another had a compass on the back.* They all used the single standard tint for matching the exposed spot on the sensitized paper.

As we mentioned in Part II of this series,[28a] the Britannia Works Company, Ltd., of Ilford, England, which in 1900, after combining with a number of other companies, became Ilford Limited, marketed the first *Ilford Exposure Calculator*, as well as the first *Ilford Exposure Meter*, a combined calculator-actinometer. The latter was advertised in the *British Journal Photographic Almanac* for 1893,[75a] and in the *Year-Book of Photography for 1893*.[75b] A description of it was given also in *Eder's Jahrbuch f. 1894*.[76]

The earliest form of Ilford actinometer-calculator was a booklet containing both the actinometer, in the form of a slot with a window, and the calculator. The sensitized paper was placed in the slot and exposed to the light at the scene to be photographed. The time that it took the spot of sensitized paper which was visible through the aperture to attain the tint of the surrounding circle of standard tint was measured and used on the slide-rule calculator to determine the correct camera exposure.

There were two booklets, one for bright light, and the other for dim light. Apparently this was the first actinometer-calculator in booklet form to be put on the market. The booklet was described and illustrated by Percy Harris in his article, "Meters and Memories," in *Modern Camera Magazine* for March 1956.[77] We reproduce here, with Mr. Harris' permission, prints which he sent us of this device (Fig. 12).

* Names and patent information on all of the Watkins' meters are not given here, but further details can be supplied by the writer to anyone doing serious research in this field.

Fig. 13. *Wynne's "Infallible" Exposure Meter*—a combined actinometer and calculator in watch form.[79a] [Photograph courtesy of George Eastman House, from a Wynne meter in its collection.]

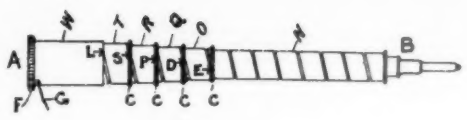


FIG. 1.

FIG. 2.

FIG. 3.

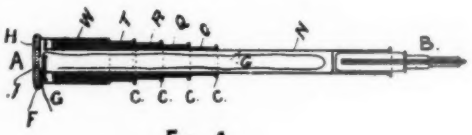


FIG. 4.

Fig. 14. Patent diagram of R. W. Savage's proposed *Pencil Actinometer* [Brit. Pat. 3,701, granted Dec. 19, 1894[81]].

G. F. Wynne, like Alfred Watkins, patented and marketed a series of actinometer-exposure meters of the watch-like type, with built-in calculators.[78a–c]† These were the basis of meters which were very popular over many years, to as late as 1939.[79a–c] There was a two-year intermission in 1918–19 due to the war. Wynne's first true actinometer patent application, in England, was dated May 30, 1893.[78a] The instrument had only two scales, arranged concentrically, one on the glass lid, and the other on the box or case. The former could be turned by means of a milled head. The actinometer consisted of a disk of standard tint having a slit under which the sensitized paper could be drawn and exposed until its tint matched the standard. The *Wynne's "Infallible" Exposure Meter*, in watch form (Fig. 13), first appeared on the market in 1894.[79a] This was preceded, as described in Part II of this series,[28a] by a miniature slide-rule type of calculator.

In 1915, there appeared a new meter, the *Wynne's "Infallible" Exposure Meter: Hunter Meter (Patent)*,[79b] which was watch-like, but with the actinometer in one half of the case, and the calculator in the other half. It also had an interchangeable top scale for Universal System (U.S.), and for *f* units, and also a scale for Autochromes. In 1918 the meters were discontinued because of the war. In 1920, the *Hunter Meter (Patent)* meters were again marketed, but the original *Standard Meter* was eliminated.[79c]

On July 20, 1893, B. J. Edwards applied for a British patent for a meter-calculator in booklet form,[80] and was granted the patent in a little less than a year. The proposed device contained a simple actinometer

† There are other Wynne patents than those indicated here.

with sensitized paper, and a slide-rule type of calculator with two fixed scales and two movable scales.

R. W. Savage, on Feb. 21, 1894, applied for a British patent on a unique actinometer-calculator.[81] It was granted in December of the same year (Fig. 14). The device had the form of a spiral slide rule. Six tubes were concentric and screwed one into the other, the scales on them representing the usual photographic factors for calculating exposure for any given plate. The actinic value of the light was determined by exposing at the end of the telescoping tube a section of a strip of sensitized paper stored in the inner tube. Two standard patches were provided, one of half the density of the other. In dull light the lower standard was to be used.

In 1898, Otto Neupert applied for a German patent[82] for a rectangular box-like actinometer, mechanically controlled.

Also in 1898, John Albert Cheape, of Charlottesville, Va., brought out an actinometer-calculator of the flat, rectangular, slide-rule type, with which, according to an article by Cheape in the *British Journal of Photography*,[83] one could "determine the strength of the actinic light in two ways, first by the slightest printing of a stencil so that any slow or fast sensitized photographic paper which prints out without development may be used; and secondly, by the printing of a paper especially preferred for the purpose, to a certain given tint."

J. Sterry, in his book, *Photography by Rule* (1903),[84] comparing some actinometers of that period, made the statement: "Experiment appears to show that the Watkins standard view [landscape] requires about one and a half times the exposure of the H & D standard, and Wynne's somewhat less than one and a quarter, but for all practical purposes the relation given in the following table is sufficiently correct." There followed a table listing comparative speeds as determined with the Watkins and Wynne meters along with H & D speeds, for Extra Rapid, Rapid, and Ordinary, Slow and Lantern Plates, from which the above conclusions were drawn.

"The following [relative] exposures are indicated for the brightest light in mid-summer. The plate is an ordinary one, having a speed of 32 H & D, and the stop is $f/45$.

"Hurter & Driffield	1 sec.
"Dibden (Cadett & Neal)	$1\frac{1}{2}$ sec.
"Lambert & Cadett	$\frac{7}{8}$ sec.
"Watkins Actinometer	1 sec.
"Wynne Actinometer	1 sec.
"Imperial Tables	3 sec.
"Ilford	2 sec.
"Burroughs & Wellcome	2 sec.
"Stanley Actinometer with Hudson's Tables	$1\frac{1}{2}$ to 2 sec.
"Columbia ditto	6 sec."

It is obvious from this that in determining exposure in those days a photographer had to stick to one make of actinometer; otherwise results would be erratic.

A very popular German exposure meter which appeared on the market in 1905 was that of Gustav Heyde, described by Eder [27, 97] in the *Photographische Korrespondenz*. The also popular device of Decoudun[98] brought out in France in 1907 was somewhat similar to it.

Two unusual actinometers were patented by H. L. Ide in the United States in 1915.[85a–d] In one of these Ide proposed that the paper backing of roll film should have fastened to it a disk of sensitized paper surrounded by an angular border of a fixed tint and adapted to be moved to a position beneath a shuttered opening in the camera back when the film is moved to a new position. Variations on this patent were later issued. The other patent applied to the tabs on film packs. Exposure tables were also provided. As far as we are aware, these patents were never used to produce devices for the general public.

Another unusual proposal was for a watch-like actinometer using sensitized paper, in which, when a pin was pressed, the paper was advanced and a stopwatch mechanism was started. This could be stopped when the desired tint was reached. Computing data were inside the cover. A United States patent for this device was granted in 1921 to W. Derichsweiler, who assigned it to Horlogerie Recta, S. A.[86]

During the last thirty-odd years, some patents have been granted on actinometers coupled with the diaphragm or with the shutter-timing mechanism of the camera, but they have come to nothing practically. However, we give some references,[87–89] including the first mention (1903) of a camera-coupled exposure meter.[87]

Another actinometer that was connected on the camera for automatic operation was invented by H. Hess, to whom a United States patent was granted in 1919. He assigned his patent to the Hess-Ives Corporation.[90] According to the patent specifications, the setting of the actinometer starts a timing device which automatically changes the adjustments of the camera, so that when the operator stops the actinometer mechanism after the exposed sensitized-paper spot matches the standard, the camera will be set for the correct exposure for the light conditions prevailing at the time.

Most of the cited silver-salt-sensitized-paper actinometers, or the patents on them, were based on the principle of matching the tint of the exposed sensitized paper against a standard tint or series of tints, and measuring the time required for the exposed paper to reach these tints. There have also been some actinometers in which the least-visible-tint principle has been used. For example, in 1918 F. M. Steadman was granted a United States patent on such a device.[91] Of course it was still necessary to have an adjacent series of standard tints of about the just-perceptible level.

Some additional actinometer exposure-meter patents and references for meters of the various types and classes described above, covering the period 1899–1943, are given in the reference list.[92–124*]

Neither early actinometers of the gaseous-chemical-

* This is not an exhaustive list. Many more United States and foreign patents were granted. Also numerous other meters of the types above described or listed in the references, including meters made in Germany, France, and other foreign countries, have appeared on the markets of the world. Space does not permit mentioning them here

reaction type nor differential thermometers achieved a great degree of popularity. The same is true of those actinometers which employed sensitized paper, until the time of the Stanley, Watkins, and Wynne meters. This can be attributed to several factors.

In the early days, photography was rather limited — confined largely to the few hardy souls, both amateur and professional, and scientific, who did not mind going to much trouble and effort in their photography or its application. To them, cumbersome equipment and complicated procedures did not make much difference. Photographic plates were comparatively slow, and until the 1870's were largely made by the photographers themselves. A science of photography had not yet been established, in spite of Herschel, Hunt, Draper, Bunsen and Roscoe, Claudet, Vogel, and some other scientists and careful investigators.

Then came, in the 1880's, the gelatin dry plates not individually made, but manufactured on a larger scale than any plates hitherto; Hurter and Driffield, with a usable scientific system of sensitometry; a more widely disseminated practical understanding by the photographic public of exposure and sensitivity; and portable, more easily handled cameras. Photography became far more popular. The amateurs were ready for a comparatively small, simple, easily understandable and workable exposure device which would help them attain a higher percentage of good exposures in their photography. Alfred Watkins, Wynne, and others, each in his own way, supplied such a device.

Yet actinometer-calculators were not ideal. While not subject to appreciable personal, i.e., visual, errors in handling, they were not highly accurate, trustworthy exposure devices under ordinary everyday conditions. Changes of weather from dry to moist, and from cold to hot, or vice versa, caused considerable changes in the light-sensitivity of the silver-halide paper. These devices were good, therefore, only for approximating exposures. If they could be kept under fairly uniform temperature and relative-humidity conditions they would then be much more reliable. But such uniformity of surroundings could not be maintained in any practical way by the average person.

However, the development of exposure meters was not confined to actinometer-calculators. There was a simultaneous development of other kinds of exposure meters, particularly of the visual photometers, which we hope to survey in a subsequent part of this series.

Acknowledgments

I wish to thank Beaumont Newhall of the George Eastman House for helpful information and suggestions; William West of the Kodak Research Laboratories, for his careful, critical review of this paper, and corrections of some errors in the manuscript; Helmut Gernsheim, of London, England, for some useful information he sent me; and R. S. Schultze, Research Librarian and Curator, Kodak Museum, Kodak Limited, England, for pointing out errors in Parts I and II, and for certain suggestions and information. I wish also to acknowledge important assistance given me by Mrs. R. P. Wightman in connection with certain references in some journals in the New York Public Library and not available in Rochester.

The writer will be grateful for any information regarding reference data which he may have overlooked and will appreciate hearing about any errors in statements or in reference data in the material published thus far.

References

1. *Introduction*

1a. Crookes, William, "On the Measurement of the Luminous Intensity of Light," *Brit. J. Phot., 15:* 352–54, July 24; 402–3, Aug. 21 (1868).
b. ———, *Phot. News, 12:* 368–70, July 31; 391–93, Aug. 14 (1868); from *Quarterly J. Sci.*
c. ———, "On the Application of Photography to the Study of Certain Phenomena of Polarization," *J. Phot. Soc., 1:* 70–73, June 21 (1853).

2. *Early Chemical Actinometers*

2a. Eder, Joseph Maria, *History of Photography*, translated by Edward Epstean, Columbia University Press, New York, 1945, "Invention of the First Chemical Photometer by Saussure, in 1770, and His Other Discoveries," p. 112.
b. *Ibid.*, "The Invention of a Self-Recording Photometer with Silver Chloride Paper, by Landrini in Vienna, 1818," pp. 169–70.
c. *Ibid.*, ["Silver Chloride Paper for Recording Maps by Sunlight," by the Swedish inventor Georg Scheutz], p. 170.
d. *Ibid.*, "Law of Photographic Reciprocity and Photometers," pp. 414–18 [mentions Malaguti and Bunsen and Roscoe].
e. ———, "Photometer," *Eder's Jahrb. f. Phot.*, 1893, pp. 393–94 [*discusses the Stanley Actinometer*].
f. ———, "Aktinometer von Gustav Heyde," *Phot. Korr., 42:* 176, Nr. 525 (1905). [Mentions the above named actinometer and that it is somewhat like the Decoudun device,[98] which actually appeared later than the Heyde device.]
3a. de Saussure, Horace Bénédict, "Effets chimiques de la lumière sur une haute montagne, comparés avec ceux qu'on observe dans les plaines," *Mémoires de l'Académie de Turin IV*, p. 44 (1790); see Ref. 2a above.
b. Crell, *Chem. Annalen, 1:* 356 (1796); see Ref. 2a above.
4a. Herschel, John F. W., "Explanation of the Principle and Construction of the Actinometer," in *Report of the Third Meeting of the British Association for the Advancement of Science, Cambridge, 1833*, John Murray, London, 1834, pp. 379–81.
b. ———, "On the Chemical Action of the Rays of the Solar Spectrum on the Preparations of Silver and Substances, both Metallic and Non-Metallic and on Some Photographic Processes. VIII. Description of an Actinograph or Self-Registering Photometer for Meteorological Purposes," *Phil. Trans. Roy. Soc. (London), 130:* 46–50 (1840); read Feb. 20, 1840.
5a. *The Oxford English Dictionary*, James Murray, Henry Bradley, W. A. Craigie, and C. T. Onions, eds., The Clarendon Press, Oxford, 1933, Vol. I, A–B, "actinometer," p. 21.
b. *Ibid.*, "actinism."
c. *Ibid.*, "actinic."
6a. *Webster's New International Dictionary of the English Language*, G. & C. Merriam Company, Springfield, Mass., 2nd ed., 1934, 1957 printing, "actinometer," p. 26.
b. *Ibid.*, "heliograph," p. 1158.

7a. Hunt, Robert, "Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants," *Report of the Brit. Assoc. Adv. Sci.*, Sept. 1844, pp. 29–32.

b. [———], "actinism," in "Dictionary of Photography — Actinism, Actinometer," *Phot. News, 1:* 139, Nov. 26; 151, Dec. 3; 163–64, Dec. 10; 175, Dec. 17 (1858).

c. ———, *Photography: A Treatise on the Chemical Changes Produced by Solar Radiation.* . . S. D. Humphrey, New York, 1852, Chap. II, "actinism," p. 11.

d. *Ibid.*, "General Remarks on the Solar Agency Producing Chemical Change," p. 9.

e. ———, *A Popular Treatise on the Art of Photography including Daguerreotype*, Richard Griffin and Company, Glasgow, 1841, "On the Use of Photographic Paper for Registering the Indications of Meteorological Instruments," pp. 87–89.

f. ———, *Researches on Light*, Longman, Brown, Green, and Longmans, 1844 [The Investigations and Experiments of Nicéphore Niepce], pp. 23–34.

g. *Ibid.*, [More exposure required in tropics than in London], p. 366.

h. ———, "On Methods for Measuring the Variations in Chemical Action of the Solar Rays," *J. Phot. Soc., 1:* 81–84, July 21 (1853).

8. Ritchie, William, "On the colorific effect of the sun's rays" [in "Additional Observations on Leslie's Photometer. . . .], *Edinburgh J. Sci., 3:* No. 5, 107, Apr.–Oct. (1825). [The whole article, pp. 104–7, is a letter to Sir David Brewster.]

9a. Becquerel, E., "Recherches sur les Effets de la Radiation chimique de la Lumière solaire, au Moyen des Courants électrique," *Compt. rend. hebd. d. l'Acad. d. Sci., 9:* 145–49 (1839).

b. ———, "Mémoire sur les Effets électriques produits sous l'Influence des Rayons solaires," *ibid.*, pp. 561–67.

c. ———, "Sur les Effets électriques qui se produissent sous l'Influence solaire," *ibid.*, pp. 711–13; presented at the Académie des Sciences, Nov. 4, 1839.

d. ———, "Des Effets produits sur les Corps par les Rayons solaires," *Ann. d'Chim. e. d. Phys.*, (3) *9:* 257–322 (1843); presented at the Académie des Sciences, Oct. 23, 1843.

10a. Davy, Humphry, *The Collected Works of Sir Humphry Davy, Bart., L.L.D., F.R.S.*, Vol. IV, *Elements of Chemical Philosophy*, ed. John Davy, Smith, Elder and Co., Cornhill, London, 1840, pp. 154–55. [Originally published in 1812; an advertisement for this first edition was dated Berkley Square, June 1, 1812. A second edition appeared in Paris and was dated Oct. 31, 1813.]

b. *Ibid.*, pp. 13–14, 52.

11a. Draper, John W., "Description of the Tithonometer, an Instrument for Measuring the Chemical Force of the Indigotithonic Rays," *Phil. Mag.* (London, Edinburgh, and Dublin), (3) *23:* 401–15, Dec. (1843).

b. ———, "On the Measurement of the Chemical Action of Light," *ibid.*, (4) *14:* 161–64, Sept. (1857).

12. Draper, John C., "Determination of the Diurnal Amount of Light by the Precipitation of Gold," *Phot. J., 6:* 24–25, Aug. 16 (1859).

13. Draper, Harry N., "The Estimation of Actinism," *Phot. J., 6:* 37–40, Sept. 15 (1859).

14a. Wittwer, W. C., "Ueber die Einwirkung des Lichts auf Chlorwasser," Poggendorff's *Ann. d. Physik u. Chem.*, (2) *94:* 597–613, No. 4 (1855).

b. ———, [Photochemical Action of Chlorine-Water], quoted by Joh. Plotnikov, in his *Photochemie.*, Wilhelm Knapp, Halle a. S., 1910, p. 75.

15a. Gulberg, Cato Maximillian, et Waage, Peter, *Etudes sur les Affinités chimiques*, Brögger & Christie, Christiania, 1867. [For earliest paper see: *Forh. Vid. Selsk. Christiania, 35:* 92, 111 (1864). A series of papers followed from then to 1879.]

b. ———, Untersuchen über die Chemischen Affinitäten, Druckerei von Brögger & Christie, Christiania (1867); also in Ostwald's *Klassiker der Exakten Wissenschaften*, Nr. 104, Wilhelm Engelmann, Leipzig, 1899.

16. Guggenheim, E. A., "Textbook Errors: Guest Column. IX: More about the Laws of Reaction Rates and of Equilibrium," *J. Chem. Educ.*, 33: 544–45 (1956).

17a. Bunsen, Robert William, and Roscoe, Henry Enfield, "Photochemical Researches," Part I, "Measurement of Chemical Action of Light," *Phil. Trans. Roy. Soc.* (*London*), *147:* 355–80 (1857); read Nov. 20 and 27, 1856.

b. ———, Part II, "Phenomenon of Photochemical Induction," *ibid.*, pp. 381–402; read Jan. 15, 1857.

c. ———, Part III, "Optical and Chemical Extinction of Chemical Rays," *ibid.*, pp. 601–20; read June 18, 1857.

d. ———, Part IV, [no subtitle], *ibid., 149:* 879–926 (1859); read May 26, 1859.

e. ———, Part V, "On the Direct Measurement of the Chemical Action of Sunlight," *ibid., 153:* 139–60 (1863); read Dec. 11, 1862; corresponding papers were published in Poggendorff's *Ann. d. Chem. u. Phys.*

18. Sebelien, John, "The Measurement of Atmospheric Actinism," *Brit. J. Phot., 46:* 11–12, Jan. 6 (1899); from an abst. in *Chemiker Ztg.*, for Nov. 2 (1898).

19a. Burnett, C. J., "On the Chromatic Illumination of Subjects to be Photographed, with Suggestions for the Registration of the Various Actinic Phenomena," *Liverpool & Manchester Phot. J., 2:* 318–20, Dec. 15 (1858).

b. ———, "On Several Forms of Actinometer," *Phil. Mag.*, (4) *20:* letter, 50–51; paper, 51–60, July (1860).

c. ———, "On Several Forms of Actinometer," *Phot. J., 7:* 8–13, Oct. 15 (1860); from *Phil. Mag.*, July (1860).

d. ———, "On New Forms of Actinometers," *ibid.*, pp. 44–45, Nov. 15; from *Phil. Mag.*, Nov. (1860).

20. Woods, Thomas, "Description of a New Actinometer," *Phot. J., 6:* 135–38, Jan. 16 (1860); from *Phil. Mag.*, Jan. (1860).

21. Lea, M. Carey, [Actinometer for Carbon Printing], *Brit. J. Phot., 14:* 464, Sept. 27 (1867).

22. Dufour, H., "A Chemical Actinometer," *Phot. News., 25:* 158–59, Apr. 8 (1881).

23a. Dessendier, Jean Emil, "A New and Improved Photometer for Use in Photography," Brit. Pat. 14,548, filed Nov. 10, 1886; accepted Nov. 8, 1887.

b. ———, "Zeigervorrichtung zur Verbindung eines Chlorknallgas-Photometers mit einem automatischen photographischen Copir-Apparate," D. R. Pat. 41,382, filed Nov. 26, 1886; accepted Nov. 3, 1887.

24. Kremer, Josef, "Actinometer and Method of Measuring the Chemical Effect of Light," Brit. Pat. 14,902, filed Aug. 3, 1893; accepted Sept. 9, 1893.

3. *Differential Thermometers*

25a. "Decisions on Disputed Inventions and Discoveries. I. Professor Leslie's Differential Thermometer Invented by Professor Sturmius," *Edinburgh J. Sci., 2:* 143–47, No. I (1825).

b. Rumford, V. P. R. S., Benjamin Count of, "An Enquiry Concerning the Nature of Heat, and the Mode of Its Communication," *Phil. Trans. Roy. Soc.* (London), *94:* 77–182 (1804); read Feb. 2, 1804.

c. We have not been able to locate a copy of Sir John Leslie's book on *Heat.*

26a. Hurter, Ferdinand, "Photometers and Actinometers," Brit. Pat. 1751, filed Apr. 23, 1881; accepted Oct. 19, 1881.

b. ———, "An Instrument for the Measurement of Diffuse Daylight and the Actinograph," *J. Soc. Chem. Ind., 9:* 370–73, Apr. 30 (1890).

27. Clark, Walter, "Actinometry, Sensitometry, and Density Measurement," *Supplement to Catalogue, 72nd Annual Exhibition, Royal Photographic Society*, 1927, p. 2; also in *Phot. J., 67:* 465–73, Nov. (1927).

28a. Wightman, E. P., "Photographic Exposure Guides and Meters. II. Exposure Tables, Charts, and Calculators," *Phot. Sci. & Eng., 2:* 19–31, June (1958).

b. ——— and Newhall, Beaumont, "Instruments for Measuring Exposure," *Image, 6:* 13–17, No. 1, Jan. (1957).

29. Ferguson, W. B. (Ed.), *Memorial Volume: The Photographic Researches of Ferdinand Hurter and Vero C. Driffield*, Royal Photographic Society of Great Britain, London, 1920, pp. 70–75.

30. Wood, C., "Variation of Photographic Exposures Throughout the Year," *Year-Bk. of Phot.*, Edited by Thomas Bolas, Piper & Carter, London, 1888, pp. 176–79.

31. Michelson, W. A., "Ein neues Aktinometer [Differential Thermometer]," *Phys. Zeitschr., 9:* 18–24 (1908).

4. *Silver-Halide and Other Standard-Tint Actinometers*

32a. Bäckstrom, Helmer, "En svensk fotografisk tillämpning för registrerings-ändamål från år 1852," *Nord. Tidskr f. Fotogr.*, *9:* 70–72, Nr. 96, Häft 4 (1925).

b. ———, "Der erste Belichtungsmesser-ein schwedischer Vorschlag vor 100 Jahren," *Phot. Korr.*, *75:* 146, Oct.–Dec. (1939).

33a. Jordan, Thomas B., "On a Mode of Registering the Indications of Meteorological Instruments," *Sixth Annual Report of the Royal Cornwall Polytechnic Society, 1838.* Printed by Jane Tratham, Falmouth; sold by Simpkin & Marshall, London, 1839, pp. 184–89 and Plate VII.

b. ———, "Description of a New Arrangement of the Heliograph for Registering the Intensity of Solar Light," *Seventh Annual Report of the Royal Cornwall Polytechnic Society, 1839, ibid.*, 1840, pp. 115–16 and Plate III.

34. Potonniée, Georges, [The Heliographic Process of Nicéphore Niepce], in *The History of the Discovery of Photography*, translated by Edward Epstean, Tennant and Ward, New York, 1936, pp. 64–67, 69–76.

35a. Malaguti, M. F., "Premier mémoire sur la Faculté qu'ont certains Liquides de retarder les Effets chimiques de la Lumière diffuse," *Ann. d. Chem. e. d. Phys.*, *72:* 5–17 (1839).

b. ———, "Ueber die Fähigkeit gewisser Flüssigkeiten die chemischen Wirkungen des zerstreuten Lichts zu verzögern," Poggendorff's *Ann. d. Chem. u. Phys.*, (2) *49:* 567–73, No. 4 (1840).

36. Arago, M. [Dominique François], *Rapport de M. Arago sur le Daguerréotype, Lu à la séance de la Chambre des Députés le 3 juillet 1839 et à l'Académie des Sciences, séance du 19 aout*, Bachelier, Imprimeur-Libraire, Paris, 1839, pp. 26–27; 48–49.

37a. Daguerre, [Louis Jacques Mandé], *Historique et Description des Procédés du Daguerréotype et du Diorama*, Alphonse Giroux et Cie, Paris, 1839, p. 65.

b. ———, L. J. M., *Daguerreotypen. Beskrifning N° 8 den V.S. märkvärdiga uppfinningen att fixera framställda bilder. . . .*, A. Bonnier förlag, Stockholm, 1839, pp. 16–17. [Footnote signed *Öfvers. anm.*]

38. Soleil, M. [J. B.] "Daguerréotype-Procédé pour Determiner à l'Avance la Durée de l'Exposition des Epreuves à la Chambre noir," *Compt. rend. de l'Acad. d. Sci.*, *10:* 842–43, May 25 (1840).

39a. Stenger, Erich, "Die ersten Belichtungszeitmesser. Ein Beitrag zur Frühgeschichte der Photographie," *Phot. Korr.*, *62:* 22–23, Nr. 1, Mar. (1926).

b. ———, "Aus der Frühgeschichte der Photographie. VI. Die ersten Belichtungszeitmesser," *Phot. Inds.*, *24:* 1326–31, Nr. 52, Dec. 27 (1926).

40. Lewandowsky, K., "Bejodungs- und Belichtungsmesser für die Daguerreotypie," *Wiener Ztg.*, No. 149 (1843); Hessler, *Encyklopädische Zeitschrift des Gewerbewesens*, *3:* 450 (1843); referred to in Martin's *Anleitung zur Photographie*, 1848, p. 56. [This reference we have been unable to verify.]

41. Heeren, [Chlorsilber-Photometer], Dingler's *Polytechn. J.*, *93:* 47 (1844); *96:* 27–28 (1845); *Gewerbeblatt für das Königreich Hannover*, 1844, p. 76; Hessler, *Jahrb. für Fabrikanten u. Gewerbetreibende*, *6:* 462 (1844); *Polytechn. Centralblatt*, *5:* 337 (1845); from Erich Stenger.[39] [Again we have been unable to verify these references.]

42a. Claudet, A., "Description of the Photographometer, an Instrument for Measuring the Intensity of the Chemical Action of Rays of Light on All the Photographic Preparations, and for Comparing with Each Other the Sensitiveness of These Different Preparations," *Phil. Mag.* (London, Edinburgh, and Dublin), *33:* 329–35, Nov. (1848).

b. ———, [Photographomètre et Dynactinomètre]. A letter, *La Lumière*, *1:* 18, Mar. 9 (1851).

c. ———, "Nouvelles Recherches sur les Foyers visuels et photogéniques. Description du Dynactinomètre, du Focimètre . . ." [Ad.]; *ibid.*, 104, Aug. 3 (1851).

43. Benard, F. A., "Dynactinomètre de M. Claudet," *ibid.*, 26–27, Mar. 23 (1851).

44. Lerebours et Secretan, "Actinomètre de M. Claudet" [Ad.], *ibid.*, 104, Aug. 3 (1851).

45. Percy, "On Methods for Measuring the Variations in the Chemical Action of Solar Rays," *J. Phot. Soc.*, *1:* 84, July 21 (1853). [Comment on Robert Hunt's paper.[7h]]

46. Schall, [Actinometer], *Cosmos*, *3:* 487 (1853); cf. Eder., *Ausführliches Handb.*, I, *1:* 384 (1892); also quoted by Erich Stenger.[39]

47. Gaudin, M.-A., "À la Mesure de la Lumière," *La Lumière*, *4:* 86–87, June 3; 89, June 10 (1854).

48. Malval, M., "Nouveau photomètre applicable à la Photographie," *Bull. Soc. franç. Phot.*, *9:* 221–23, Aug.-Sept. (1863).

49a. Roscoe, Henry Enfield, "The Bakerian Lecture—On a Method of Meteorological Registration of the Chemical Action of Total Daylight," *Phil. Trans. Roy. Soc.* (London), *155:* 605–31 (1865); read Dec. 22, 1864.

b. ———, "On the Chemical Intensity of Total Daylight at Kew and Pará, 1865, 1866, 1867," *ibid.*, *157:* 555–69 (1867); read June 20, 1867.

c. ——— and Thorpe, T. E., "On the Relation Between the Sun's Altitude and the Chemical Intensity of Total Daylight in a Cloudless Sky," *ibid.*, *160:* 309–16 (1870); read Mar. 31, 1870.

d. ———, ———, "On the Measurement of Chemical Intensity of Total Daylight Made at Cantania During the Total Eclipse of Dec. 22, 1870," *ibid.*, *161:* 467–76 (1871); read June 15, 1871.

e. ———, "On a Self-Recording Method of Measuring the Intensity of the Chemical Action of Total Daylight," *ibid.*, *164:* 655–73 (1874); read Feb. 5, 1874.

50. [Editor], "Improvements in Actinometers," *Brit. J. Phot.*, *21:* 408, Aug. 28 (1874).

51. Swan, J. W., "On a Photographic Actinometer," *Brit. J. Phot.*, *13:* 125–26, Mar. 16 (1866); read before the London Photographic Society, Mar. 13, 1866.

52a. Vogel, Herman, "A New Photometer," *Brit. J. Phot.*, *14:* 434, Sept. 13 (1867); from *Phot. Mittheil. Sitzb.*, 1866–67, p. 45.

b. ———, *The Chemistry of Light and Photography . . .*, D. Appleton and Company, New York, 1882, "The Photometer," pp. 254–55.

53a. [Editor], "A New Actinometer for Carbon Printing," *Brit. J. Phot.*, *17:* 576–77, Dec. 9 (1870). [Mainly about the *Spencer Actinometer*.]

b. ———, "A New Form of Actinometer," *ibid.*, *22:* 302–3, June 25 (1875).

54. Johnson, J. R., "On a New Actinometer; and on a New Method of Regulating the Exposure of Pigment Pictures," *Brit. J. Phot.*, *19:* 604–5, Dec. 20; 615–16, Dec. 27 (1872).

55. Debenham, W. E., "A New Actinometer," *Brit. J. Phot. Almanac*, 1878, pp. 115–17.

56. Illingworth & Co., Thomas, "A New Actinometer for Carbon Printing," *Brit. J. Phot.*, *49:* 433, May 30 (1902).

57. Autotype Co., London, "Disc Actinometer," *Brit. J. Phot.*, *49:* 535, July 4 (1902).

58. Akt.-Ges. Geka-Werke, Der (Hanau), "Das Flexoid-Photometer," Eder's *Jahrb. f. Phot. u. Reproduktionstech.*, 1906, p. 15.

59. Vobach, Willy (Berlin), "Verfahren zur Herstellung von Chromatgelatinekopien," D. R. Pat. 360,633, filed July 13, 1921; accepted Oct. 5, 1922.

60a. Bing, Louis, "Actinometers," Brit. Pat. 2355, filed Sept. 13, 1866 (provisional protection only); from *Abridgements of Specifications*, Class 98, "Photography," Patent Office, London, 1905, p. 57.

b. ———, "An Improved Mode of and Apparatus for Ascertaining the Actinic Power of Light," Brit. Pat. 1297, filed Apr. 21, 1868; accepted Oct. 21, 1868.

c. ———, "On Actinometry," *Phot. News*, *12:* 416–18, Aug. 28 (1868).

61. [Editor], "Mr. Bing's New Actinometer," *Phot. News*, *12:* 422, Sept. 4 (1868).

62a. Abney, W. de W., "On the Measurement of the Actinic Value of Sunlight," *Brit. J. Phot.*, *23:* 246–48, May 26 (1876).

b. ———, "On the Measurement of the Actinic Value of Sunlight," *Phot. News*, *20:* 242–43, May 26 (1876).

c. ———, "On Actinometers," *Brit. J. Phot. Almanac*, 1876, pp. 53–54.

63. Batho, W. E., "An Actinometer," *Brit. J. Phot.*, *22:* 113–14, Mar. 5 (1875).

64. Hemagis, M., "Correspondence—The *Photomètre à Prisme*," *Brit. J. Phot.*, *22:* 610–11, Dec. 17 (1875).

65. "C. P.," "Actinometers for Landscape Work," *Brit. J. Phot.*, *24:* 580, Dec. 7 (1877).

66. Green, Cleveland, and Füidge, Louis Varley, "A New Improved Actinometer," Brit. Pat. 14,457, filed Nov. 1, 1884; accepted Mar. 18, 1885.

67. Vidal, Léon, "Pose-Photomètres négatifs," in *Manuel du Touriste Photographie*, Gauthier-Villars, Paris, 1re Pt., 1885, pp. 193-204.

68a. Stanley, William Ford, "Actinometer for Photography," Brit. Pat. 4,528, filed Apr. 13, 1885; apparently abandoned.
b. ——— and Sarjeant, William Low, "Actinometers for Photography," Brit. Pat. 4,624, filed Mar. 31, 1886; accepted Apr. 2, 1886.

69a. Stanley, Manufacturer (London), "New Patent Actinometer" [Adv.], *Brit. J. Phot. Almanac*, 1886, p. CXLVIII.
b. ———, "Stanley's New Patent Actinometer," *ibid.*, 103 (1890).

70a. Watkins, Alfred, "Mathematical Calculation of Exposures and a New Exposure Meter," *Brit. J. Phot.*, *37:* 247–48, Apr. 18; 262, Apr. 25 (1890).
b. ———, "An Instrument for Calculating Photographic Exposure," Brit. Pat. 1,388, filed Jan. 27, 1890; accepted Nov. 15, 1890; U.S. Pat. 456,869, filed Nov. 20, 1890; accepted July 28, 1891. [Cylindrical type.]
c. ———, "The Watkins Exposure Meter" [Adv.], *Brit. J. Phot. Almanac*, 1890, p. 69.
d. ———, "Improvements in Instruments for Calculating Photographic Exposures," Brit. Pat. 14,364, filed July 25, 1893; accepted Sept. 16, 1893. [Cylindrical type.]
e. *Ibid.*, 25,000, filed Dec. 22, 1894; accepted Feb. 9, 1895. [Watch-like type.]
f. ———, "Photographic Exposure Meter," U.S. Pat. 657,685, filed July 5, 1899; accepted Sept. 11, 1900. [Watch-like type.]
g. *Ibid.*, 725,807, filed June 5, 1901; accepted Apr. 21, 1903.

71. Haines, W. E., Herford, "The *Watkins' Exposure Meter* (Patent Pending)" [Adv.], *Year-Bk. of Phot.*, 1891, p. lxxxiii. [Cylindrical-type meter.]

72a. Field & Co., R., Birmingham, "*Watkins' Exposure Meter*" [Adv.], *ibid.*, 1893, p. 627.
b. ———, "Watkins' Exposure Meters" [Adv.], *ibid.*, 1897, p. 618. [Cylindrical-type and multiple-scale-disk-type meters.]
c. ———, "Watkins' Exposure Meters" [Adv.], *Brit. J. Phot. Almanac*, 1897, p. 367. [*The Watch*, the first watch-like meter; *The Standard*, cylindrical meter; *The Junior*, cylindrical meter; and *The New Hand-Camera Meter*, a disk meter.]

73a. Watkins Meter Co., Hereford, "Watkins Exposure Meters" [Adv.], *Year-Bk. of Phot.*, 1907, p. 105. [*The Standard*, and *The New Hand Camera Meter.*]
b. ———, "The Bee Meter," "Queen Bee," "Standard Meter" [Advs.], *Brit. J. Phot. Almanac*, 1907, pp. 444–45. [Watch-like meters and cylindrical meter.]
c. ———, "Bee Meter; and Small Cine Meter—for All-Around Photography" [Adv.], *ibid.*, 1931, p. 66. [Watch-like meters.]

74. Anon., "The Watkins' *Snipe Meter*," *Brit. J. Phot.*, *67:* 486, Aug. 6 (1920).

75a. Britannia Works Company, Ltd., Ilford, London, "*Ilford Exposure Meter*, by Prof. Scott" [Adv.], *Brit. J. Phot. Almanac*, 1893, pp. 793, 794, 796.
b. ———, "Ready in a Few Days—Prof. J. Alfred Scott's *Ilford Exposure Meter*" [Adv.], *Year-Bk. of Phot.*, 1893, p. 647.

76. Anon., "Ilford Expositionsmesser (Professor A. Scott's Patent)," Eder's *Jahrb. f. Phot. . . .*, 1894, pp. 361–62.

77. Harris, Percy W., "Meters and Memories," *Modern Camera Mag.*, *20:* 114–15, Mar. (1956).

78a. Wynne, George Frederick, "Improvements in Apparatus for Calculating Photographic Exposures," Brit. Pat. 10,617, filed May 30, 1893; accepted Apr. 14, 1894; U.S. Pat. 557,246, filed Jan. 25, 1894; accepted Mar. 31, 1896.
b. ———, "Actinometer," U.S. Pat. 600,484, filed Feb. 12, 1897; accepted Mar. 8, 1898.
c. ———, "Apparatus for Calculating Photographic Exposures," U. S. Pat. 1,194,919, filed Mar. 3, 1915; accepted Aug. 15, 1916; corresp. to Brit. Pat. 6,380, 1914.

79a. The Infallible Exposure Meter Co., Wrexham, Eng., "*Wynne's Infallible Exposure Meter*" [Adv.], *Brit. J. Phot. Almanac*, 1894, p. 1314.
b. ———, "*Wynne's 'Infallible' Exposure Meter: Hunter Meter* (Patent)" [Adv.], *ibid.*, 1920, p. 647.
c. *Ibid.*, 1939, p. 56. [Also an ad for *Wynne's Infallible Print Meter*, p. 771.]

80. Edwards, B. J., "Improvements i Photographic Apparatus," Brit. Pat. 14,074, filed July 20, 1893; accepted June 23, 1894.

81. Savage, R. W., "Improvements in Instruments for Calculating Photographic Exposures," Brit. Pat. 3,701, filed Feb. 21, 1894; accepted Dec. 29, 1894.

82. Neupert, Otto, "Mechanisches Photometer," D. R. Pat. 103,161, filed Aug. 31, 1898; accepted May 23, 1899.

83. Cheape, John Albert, "*Cheape's Actinometer*," *Brit. J. Phot.*, *45:* 745–46, Nov. 18 (1898).

84. Sterry, J., *Photography by Rule*, Iliffe & Sons, Ltd., 1903, Chap. III, "Comparison of Exposure Tables and Meters," pp. 43, 44.

85a. Ide, Harry Lord, "Actinometer," U.S. Pat. 1,170,538, filed Apr. 5, 1915; accepted Feb. 8, 1916.
b. ———, assigned ½ to Roy W. Ide, "Photographic Camera," U.S. Pat. 1,208,320, filed Oct. 23, 1915; accepted Dec. 12, 1916. [A minor variation of the earlier patent.[85m]]
c. ——— and Ide, Roy Wm., "Photographic Camera," Brit. Pat. 12,452, filed Aug. 30, 1915; accepted Apr. 6, 1916; dup. of U.S. Pat. 1,170,538.[85m]
d. *Ibid.*, 107,890, filed Oct. 12, 1916; accepted July 19, 1917.[85e]

86a. Derichsweiler, Walram (Zürich, Schweiz.), U.S. Pat. assigned by Mesne Assignments to Fabrique d'Horlogerie Recta, S. A., "Photographic Exposure Meter," Brit. Pat. 111,409, filed Mar. 16, 1917; accepted Nov. 19, 1917; U.S. Pat. 1,377,564, filed Apr. 14, 1917; accepted May 10, 1921.
b. ———, "Photographischer Belichtungsmesser," D. R. Pat. 356,873, filed June 14, 1921; accepted Aug. 2, 1922.

87. Mertens, Eduard, "Photometriches Verfahren, bei dem die Lichtmessung durch Vergleichung von durch Einwirkung von Licht und von Entwicklern auf stark lichtempfindlichen Schichten entstekenden Färbungen mit festgelegten Farben geschicht," D. R. Pat. 176,319, filed Nov. 3, 1903; accepted Oct. 17, 1906.

88. Gray, J., "Photographic Exposure Meter," Brit. Pat. 225,902, filed July 16, 1923; accepted Dec. 16, 1924.

89. Schimmelpfennig, Friedrich (Germany), "Perfectionnement aux appareils photographiques," Brevet d'Invent. 669,356, filed Feb. 8, 1929; accepted Aug. 3, 1929.

90. Hess, H., assigned to Hess-Ives Corp., "Photographic Camera Exposing Mechanism," U.S. Pat. 1,300,613, filed Feb. 4, 1916; accepted Apr. 15, 1919.

91. Steadman, F. M., "Device for Determining the Actinic Power of Light," U.S. Pat. 1,274,464, filed Dec. 22, 1915; renewed Dec. 13, 1917; accepted Aug. 6, 1918.

92. Randall, John A., "Actinograms and a Self-Recording Actinometer," *Brit. J. Phot.*, *46:* 426–27, July 7 (1899). [Device for obtaining a continuous record of daylight on roll film by means of step-wedge densities.]

93. Acworth, Joseph John, and The Imperial Dry Plate Co., Ltd., Crinklewood, London, "Improved Apparatus for Estimating Photographic Exposure," Brit. Pat. 3873, filed Feb. 23, 1901; accepted Dec. 21, 1901. [A tablet form of actinometer-calculator.]

94. Carl Ernst & Co., Akt.-Ges. (Berlin), "Belichtungsmesser für photographische Aufnahmen mit unter einer Photometerskala zu belichtendem lichtempfindlichen Papier," D. R. Pat. 163,157, filed July 23, 1904; accepted Sept. 28, 1905. [A tablet form with standard step-wedge. The exposed series of steps is placed over a calibrated movable scale.]

95. Rothenbucher, Alexander, "Expositionsmesser für photographische Aufnahmen," D. R. Pat. 172,541, filed June 18, 1905; accepted June 23, 1906. [A circular multiple-disk-type actinometer.]

96. Hilsdorf, Hans (Bingen, Germany), "Photometer, bei dem der lichtempfindliche Streifen auf der Grundplatte gehalten und der die Skala tragende Deckel an der Grundplatte angelenkt ist," D. R. Pat. 175,967, filed Sept. 26, 1905; accepted Oct. 18, 1906; see also *Photo Chronik*, *14:* 101, Feb. 17 (1907).

97. Heyde, Gustav (Dresden, Germany), "*Heydes Aktino-Photometer*," [Adv.], in Eder's *Jahrb. f. Phot.* . . ., 1905, p. 41; to 1910, p. 13. [First acared in 1905; see also Ref. 2f above.]

98. Decoudun, M. Jules, "Actino-photomètre pour determiner le temps de pose en photographie," Brevet d'Invent. 379,810, filed July 11, 1907; accepted Sept. 18, 1907. [A compact, box-like actinometer; see also Ref. 2f above.]

99. Rietzschel, A. Hch., (G.M.B.H., München), "Photographischer Belichtungsmesser, bei welchem die Zeit festzustellen ist, innerhalf deren ein lichtempfindliches Papier bis zu einer Vergleichsfarbe angedunkelt ist," D. R. Pat. 203,413, filed Dec. 14, 1907; accepted Oct. 23, 1908. [A watch-like actinometer.]

100. Walloon, M. E., "Le Crible photomètrique de Simon-Français," *Bull. Soc. franç. Phot.*, *24:* 117–29, No. 6 (1908); presented at the Feb. 21, 1908, session. [An actinometer-calculator with the name *Crible photomètrique*, using the least visible number principle.]

101a. Scheffer, W., (Berlin-Wilmersdorf), "Photometer," D. R. Pat. 250,815, filed Dec. 7, 1911; accepted Sept. 20, 1912; see *Phot. Inde.*, Heft 41: 1427 (1912). [An actinometer with a series of standard densities.]

b. ———, D. R. Pat. 252,414, filed Feb. 18, 1912; accepted Oct. 17, 1912; addition to Pat. 250,815,[101a] filed Dec. 7, 1911.

102. Schäffer, Adolf, (München), "Belichtungsmesser," D. R. Pat. 332,621, filed Aug. 8, 1919; accepted Feb. 3, 1921. [A watch-like actinometer.]

103. Boucher, P., (Paris), "Photographischer Apparat (Zur genauen Bestimmung der zur Belichtung von ein- und mehrfarbigen photographischen Platten erforderlichen Zeitdauer)," Oesterreich. Pat. 4729, filed May 31, 1912; accepted Dec. 15, 1912. [A cylindrical-type actinometer with scale of standard tones.]

104. [Lumière-Jougla-Werke], "Neukeitenbericht: Chronoscop-Photometer," *Phot. Inde.*, *10:* 1680–81, Heft 48, Nov. 27 (1912). [Actinometer with 4-step standard scale, intended for use in determining exposure of Autochrome plates.]

105. Lang, Louis, trading as Emil Wünsche Nachfolger (Dresden-Alt., Germany), "Improvements in and Relating to Actinometers," Brit. Pat. 13,459, filed June 10, 1913; accepted June 4, 1914. [Watch-like actinometer.]

106. Wünsche, Emil (Dresden), "Ein chemischen Belichtungsmesser," D.G.M. 577,009, 1914;* see: Eder's *Jahrb. f. Phot.* . . ., 1914, pp. 326–27. [A watch-like actinometer.]

107a. Müller & Vaucher, A. G., (Biel, Schweiz.), "Belichtungsmesser für photographische Zwecke," D. R. Pat. 299,500, filed Mar. 17, 1915; accepted July 20, 1917. [A watch-like actinometer with a seconds and minutes (stop-watch) timer.]

b. *Ibid.*, 300,205, filed Apr. 30, 1916; accepted Aug. 21, 1917. [Watch-like actinometer.]

108. Fabrique d'Horlogerie Recta, S. A. (Biel, Schweiz.), "Photographischer Belichtungsmesser," D. R. Pat. 320,891, filed Apr. 28, 1916; accepted May 6, 1920. [A watch-like actinometer, with operation control through a mechanism in the stem.]

109. Jacoby, Arthur (Cassel, Germany), "Photographischer Belichtungsmesser," D. R. Pat. 339,304, filed Sept. 8, 1917; accepted July 20, 1921. [Stop-watch controlled actinometer.]

110. Baumgart, Otto (Berlin), "Verfahren und Vorrichtung zur Ermittlung der Belichtungszeit," D. R. Pat. 318,142, filed Sept. 24, 1918; accepted Jan. 14, 1920. [A folding tablet-like actinometer attached to a rectangular compartment to hold the sensitized paper.]

111. Ellicott, V. L., "Method of and Apparatus for Determining Photographic Exposures," U.S. Pat. 1,385,940, filed Jan. 14, 1920; accepted July 26, 1921. [Tablet-form actinometer.]

112. Sieber, Hermann (Düsseldorf), "Verfahren zum Messen aktinischer Strahlemengen," D. R. Pat. 366,042, filed Mar. 19, 1921; accepted Dec. 28, 1922. [Utilizes a gelatin layer sensitized with silver nitrate and silver nitrite for measuring actinic power of light.]

113. Mathéron, Robert-Antonin, "Appareil servant à déterminer le temps de pose en photographie," Brevet d'Invent. 547,510, filed May 18, 1921; accepted Sept. 25, 1922. [A slide-rule type of actinometer-calculator.]

114. Wandersleb, E. (Jena, Germany), "Exposure Meter," U.S. Pat. 1,457,802, filed June 5, 1923; accepted Aug. 29, 1921. [An actinometer arranged on a camera with an optical sighting device.]

115a. Slichter, Wilhelm (Freiburg, Germany), "Neue Hilfsmittel zur planmässigen Beherrschung des photographischen Negativprocesses, *Zeit. tech. Physik.* 3: 63–64 (1922). [Describes a meter in which an actinometer is used to determine the light intensity and a visual photometric device is used to compare light gradations of the subject.]

b. ———, "Photographic Photometer," U.S. Pat. 1,482,441, filed Nov. 20, 1923; accepted Feb. 5, 1924. [A cylindrical-type actinometer equipped with light filters for control of the light intensity.]

c. ———, "Improvements in or Relating to Photographic Photometers," Brit. Pat. 234,147, filed Dec. 17, 1923; accepted May 18, 1925; duplicate of D. R. Pat. 385,107. [A combined optical and actinometric meter.]

116. Emmerman, C., "Belichtungsmesser II—Schlichterische Photometer," *Filmtechnik*, *2:* 323–25, Aug. 7 (1926). [Describes and discusses the Schlichter actinometer-photometer.]

117. Pathé Cinéma, "Actinomètre," Brevet d'Invent. 564,452, filed Mar. 28, 1923; accepted Oct. 19, 1923. [Slide-rule type intended for use with a cine camera.]

118. Devos, Sylvain, et Dufour, Robert (Belgium), "Appareil pour mesurer et enregistrer l'intensité de la lumière, et tables pour son application à la photographie," Brevet d'Invent. 611,805, filed Jan. 20, 1926; accepted July 17, 1926. [Either a tablet- or disk-type actinometer.]

119. Ramsay, George, "Exposure Meter," U.S. Pat. 1,651,151, filed Oct. 14, 1926; accepted Nov. 29, 1927. [Flat cylindrical type with spring to actuate a timer.]

120a. Kehlstadt, Hans Rikli, "Exposure Meter for Photographic Purposes," Brit. Pat. 279,817, filed Oct. 7, 1927 (in Germany Oct. 29, 1926); accepted June 21, 1928. [Sensitized paper shielded from extraneous light.]

b. ———, "A Light-Measuring Photometer or Exposure Guide," D. R. Pat. 492,743, filed Oct. 30, 1926; accepted Feb. 27, 1930; Dup. of Brit. Pat. 279,817; see also U.S. Pat. 1,800,644. [The light affecting the instrument is restricted by a hood.]

121. Frey, Anton (Amberg, Germany), "Belichtungsmesser," D. R. Pat. 539,613, filed Dec. 11, 1928; accepted Nov. 28, 1931. [Tablet-type actinometer.]

122. Neidbardt, Karl, "Vorrichtung zur Lichtmessung für photographische Aufnahmen," D. R. Pat. 550,603, filed Apr. 28, 1932; accepted May 12, 1932. [Cylindrical type with a scale of standard densities.]

123. Plisker, Herbert E., Assigned to Westinghouse Lamp Co., "Light Intensity Indicator," U.S. Pat. 2,046,409, filed Aug. 8, 1934; accepted July 7, 1936. [A simple actinometer with sensitized paper and a photometric standard scale for comparison.]

124. Rath, Karl, "Visual Photographic Exposure Meter," U.S. Pat. 2,379,103, filed Nov. 18, 1943; accepted June 26, 1945. [An actinometer with an optical wedge for determining the least visible tint.]

* We have been unable to verify this patent.

Errata in Parts I and II [*P S & E*, 2: 14-31 (June 1958)]

Dr. R. S. Schultze, Research Librarian, and Curator of the Kodak Museum, Kodak Limited, Wealdstone, Harrow, England, has pointed out the following errors in the Reference List and Bibliography (2: 28–31) of Parts I and II.

References

Ref. 8, line 2: "1a," not "a1." "Députés," not "Députes."
Ref. 10, line 2: "la chambre," not "le chambre."
———, *line 4:* "la Séance," not "le Séance."
Ref. 15d, line 1: "Règles," not "Règeles."
Ref. 24b, line 1: "elektrischem," not "elektrischen."
———, *line 2:* "Stronstärke," not "Strometärke."
Ref. 24c, line 1: "elektrischem," not "elektrischen."
———, *line 2:* "Himmelslicht," not "Himmelsclicht."

Bibliography, Part I

Pizzighelli, G., line 1: "chemisch wirksamen," not "chemischewirksamen."
———, *line 3:* "Gegenwart," not "Regenwart."

Bibliography, Part II

Rickman, William George, line 2: "réduite," not "reducte." "l'intensité," not "l'intemite."
Franke u . . ., line 2: "Geschwindigkeitseinstellung," not "Aeschwindigkeitseinstellung."

Clark's *Actinometry* . . .

Dr. Schultze points out that Clark's *Actinometry, Sensitometry, and Density Measurement*, Ref. 5, was published also in *Phot. J.*, 67: 465–73, Nov. (1927), which is more easily accessible than the *Supplement to the Royal Photographic Society Catalogue*.

Albanus/Albinus

Dr. Schultze states that he has "made some researches in the literature about the author Albinus or Albanus [Part II, p. 19, and Refs. 16 and 17], the spelling of whose name is queried."

"I have found," he says, "that he is quoted three times in various volumes and editions of Eder's *Handbuch;* in two cases his name is spelt as Albinus, and only once, viz. in the latest (1932) version of Eder's *History*, is his name given as Albanus. The most complete quotation will be found in Vol. II, Part 3, page 4 (1927) [of Eder's *Handbuch*], where it appears as follows:

"C. F. Albinus, 'Der Vollkommene Daguerreotypist' (Leipzig, Berger, 1844).

"Elsewhere in Eder a book by Albinus and Seidemann, 1844, is referred to.

"There is no book by Albinus or Albanus in the Library of the Royal Photographic Society, and he is not mentioned in the earliest German-language history of photography, that by Schiendl."

• Book and Journal Reviews

Progress in Photography 1955–1958

D. A. Spencer, Editor-in-Chief, Focal Press, London, 1958, and Macmillan, New York, 1959, 168 pp.

As the volume of literature in nearly all fields of science and engineering continues to increase at a rapid pace, the worker in these fields finds the task of keeping abreast of the progress in his own specialty, let alone bordering fields, a truly formidable one. For the border fields, he is dependent more and more on "digested" versions of original articles, such as the excellent abridgments which L.-P. Clerc publishes in the photographic fields, on the various abstracting services, and on authoritative review articles. The latter, when well prepared, can be highly useful in giving the reader a general picture of the field reviewed, and in directing his attention to the pertinent literature when he wishes more details.

The series of books on *Progress in Photography*, of which this is the third and last, contains a group of authoritative reviews of progress in various fields of photography covering particular periods of time. The title of the present volume is misleading in that the book does not present the progress in *photography* over the stated period, but rather the progress in certain phases of photography. Even in the fields which are treated specifically, some of the articles cover periods other than 1955–58. Nevertheless, several of the articles represent thorough surveys of the specific topics, and the book should be of interest and value to the photographic scientist and engineer.

A review of the contents of the book will serve to indicate both what is covered and what is not. The first section contains four articles on "practice and new techniques." The paper on xerography, by Chester F. Carlson, covers the period 1951–1957. Image transfer processes, chemical and physical, are reviewed by J. Bylemans. Thermo-Fax is described briefly (less than a page) by Marie-Louise Sevenans. Amateur color print processes of Agfa, Gevaert, Ferrania, Kodak, Ilford, Ansco, and Pakolor are described by W. Lyle Brewer and illustrated by prints mounted in the volume.

Section Two is on photographic theory and materials. It includes papers on photographic sensitivity and latent image formation by J. W. Mitchell, the mechanism of development by W. Jaenicke, Russian work on the theory of photographic emulsions by K. V. Chibisov, and new film supports by C. Weyn. Section Three is devoted to a series of articles on statistics of the photographic business in Belgium (1950–55), France (1952–56), German Federal Republic (1950–57), Great Britain (1950–57), Italy (1953–55), Japan (1949–56), and USA (1950–56). Section Four deals with photographic literature and consists of articles on photographic libraries and archives in Great Britain by R. L. Collison, historiography of photography by Beaumont Newhall, and Russian literature on the photographic process by V. I. Sheberstov. Section Five is headed "applications" and consists of articles on new methods of motion-picture presentation by Gordon A. Chambers, photographic photometry by H. von Klüber, and photomechanical resists by E. E. Loening.

The article by Sheberstov contains information not readily available elsewhere on Russian publications and translations of foreign books over a period of about 30 years. The papers by Mitchell and Jaenicke cover a relatively large amount of literature in their respective fields and on an international scale. Some of the other articles are much more restricted in scope and coverage. — *T.H.J.*

Zhurnal Nauchnoi i Prikladnoi Fotografii i Kinematografii, Vol. 3, No. 4, July-August 1958

Resumés by S. C. Goddard

Study of the Process of Formation of Primary Centers in a Real Emulsion

Zh. L. Broun. Pp. 246–50

Samples of an ammoniacal silver bromide emulsion were taken at intervals during digestion for spectrophotometric and sensitometric study, the differential spectrophotometric method of E. A. Kirillov being used to obtain the fine structure of the spectra. The spectral curves corresponding to different times of digestion display peculiar changes which may be explained by a redistribution of elementary silver in the impurity centers, this redistribution occurring in a fashion similar to that of Ostwald ripening. It is suggested that one of the causes of the fall in sensitivity after the maximum during digestion is a decrease in the concentration of small centers.

Role of Nuclei in the Chemical Ripening (Digestion) of a Photographic Emulsion

I. M. Ratner. Pp. 251–55

A distinction is made between sensitivity centers and the nuclei on which they form. During physical ripening, the nuclei present on the surface of the small crystals are, to a large extent, converted into internal nuclei, so that the number present on the surface at the beginning of digestion is comparatively small. The formation of additional surface nuclei and the formation of sensitivity centers on the existing nuclei proceed simultaneously, with the result that centers at different stages of growth are present at any one time, some of them having reached the stage

of fog centers. For the highest sensitivity, the growth of the centers should be uniform, so that fog centers are not formed before the majority of the centers have reached their optimum size. To test this hypothesis, a silver bromide emulsion with 3 mol percent silver iodide was prepared and, after physical ripening, was brought to a pH of 9.5. A uniform deposition of nuclei was brought about by the addition of small quantities of the following reagents: allylthiourea, potassium thiocyanate, sodium sulfite, sodium thiosulfate, and hydrazine hydrate. The treated emulsion was held at the ripening temperature (45° C) for another 10 min, then washed and digested in the usual way, samples being taken at intervals for sensitometric testing. As predicted, higher speeds were obtained when the nuclei-forming reagents were used. Supplementary experiments were performed to study the influence of pH, washing, and temperature on nuclei formation.

Spectrophotometric Study of Solutions of Dyes Forming H-Aggregates

A. V. Borin and I. A. Pobedonostseva. Pp. 256–66

A study was made of the absorption spectra of sensitizing dyes showing H-absorption bands in aqueous solutions of gelatin. The intensity of the H-bands increases and reaches a maximum value as the concentration of the gelatin in solution is increased, the critical concentration of gelatin, corresponding to the maximum intensity of the H-band, depending on the degree of aggregation of the gelatin. In a solution made up with a gelatin having a lower degree of aggregation, the critical concentration is smaller in comparison with that of solution containing a gelatin of higher degree of aggregation. The suggestion is made that the decrease in the critical concentration for the less-aggregated gelatins is determined by the raised adsorptive activity of the micelles, as a result of which the concentration of dye adsorbed onto the gelatin micelles is increased. When the concentration of gelatin is raised above the critical value, the intensity of the H-bands decreases, apparently as the result of the increase in the solution of the concentration of decomposition products of gelatin, hindering the adsorption of the dye molecules onto the gelatin micelles or showing a peptizing action on the dye. As a result, the concentration of the molecular form of the dye in solution increases at the expense of the H-aggregates. The substitution of the hydrogen of the polymethine chain of the thiacarbocyanine dyes by groups which destroy the planarity of the molecule makes the formation of H-aggregates more difficult.

Influence of the Optical Properties of the Base on the Resolving Power of Highly Dispersed Photographic Layers

E. D. Parshin. Pp. 267–70

The effect of the base on the resolving power of a light-sensitive layer is of some concern in the manufacture of measuring scales and reticules by photographic methods. A series of determinations of resolving power were carried out on materials sensitized by the methods of Goldberg, Lippmann, and Elvegård. To study the effects of reflection and diffusion, three limiting cases were considered, in addition to that of a coating on clear glass: aluminum foil and polished chromium-plated copper sheet; opal glass and white celluloid; and the light-sensitive layer without a base. The results are tabulated.

Minimum Gradient of a Photographic Material Corresponding to the Solution of a Given Visual Task

G. A. Istomin. Pp. 271–74

For recognition of a photographic image against its background, the following inequality must hold: $K_t \cdot g_{min} > \Sigma$, where K_t is the contrast of the optically formed image, g_{min} is the minimum gradient of the photographic material, and Σ is the threshold contrast-sensitivity of the eye. For a given K_t, Σ and g_{min} depend on two groups of factors: those determined by the visual task, e.g., brightness of the adapting field, angular dimensions of the object, required accuracy of observation; and those connected with the properties of the photographic material and the conditions of exposure and development. Experiments were carried out to study the influence of development, lighting conditions during exposure, and the resolving power on the minimum gradient required for two tasks, the recognition of fine and of coarse detail. The results are given graphically. The effects are complicated because factors in development which increase the gradient also increase the graininess of the image, so that Σ increases, while lighting conditions that lower g_{min} also increase the resolving power. It is concluded that g_{min} is a useful criterion of the requirements of a visual task.

Spectrozonal Photography. II. Chromatic and Achromatic Shadow Detail: A Measure of the Mutual Influence of Spectrozonal Images

A. N. Iordanskii. Pp. 275–78

The concepts of chromatic and achromatic detail density (ΔD_{chr} and ΔD_{achr}) are defined and proposed as measures of the difference of two-color images of objects. A method is proposed for calculating the values of ΔD_{chr} and ΔD_{achr} as functions of the spectral brightness coefficients of the photographed objects for two monochromatic radiations and two spectral zones.

New Synthetic Materials for Photographic Film Bases

F. S. Sherman. Pp. 295–99

The synthesis and properties of polycarbonate, as manufactured by the German firm of Bayer, are reviewed, and some comparison is made with Cronar and other materials.

Review of Soviet Work on the Photographic Action of Ionizing Particles

A. L. Kartuzhanskii and B. P. Soltitskii. Pp. 299–306

Fifty-three articles by Soviet authors are reviewed.

Tekhnika Kino i Televideniya, September 1958

Resumés by S. C. Goddard

Electromagnetic Damping and Its Use in Electromechanical Light Modulation

Z. V. Tsirulina. Pp. 36–41

Electromagnetic damping provides the necessary attenuation of resonance frequencies in light modulators of the electromagnetic type with a simple moving system having small mass and dimensions, where a strong magnetic field can be built up in the working gap of the magnetic circuit. Formulas are derived for calculating the parameters of a ribbon oscillograph in which complete correction of the frequency characteristic is attained.

Method of Calculating a Condenser with Spherical Surfaces for Cinematograph Projectors with Incandescent Lamps

V. V. Petrov. Pp. 49–56

A method is described for calculating the radii of curvature of a condenser, with the aim of reducing the spherical aberration associated with this type of lens. It is intended for condensers used in 35mm and 16mm projectors with incandescent lighting. A specimen calculation is carried out in full for the design of a condenser for a 16mm projector.

Machines for Coating Ferromagnetic Suspensions on Motion-Picture Film

K. Kh. Sutyushev and M. B. Khalameiler. Pp. 57–63

Two machines have been built in the Moscow Constructional Bureau for Motion-Picture Apparatus for coating magnetic suspensions on 35mm, 16mm, and 32mm film. Constructional details of the 16mm machine and its control system are given.

Zhurnal Nauchnoi i Prikladnoi Fotografii i Kinematografii, Vol. 3, No. 5, September-October 1958

Resumés by Samuel Kitrosser

National Sensitometric Standards

G. S. Baranov and E. D. Katsenelenbogen. Pp. 394–98

The IX International Photographic Congress failed to agree on a common viewpoint on the problem of speed evaluation for black-and-white photographic materials. While the majority of national systems make use of characteristic curves to determine speed, contrast, and latitude, each national standard varies. A comparison of the following standards was carried out: GOST 2817–50 (USSR), DIN 4512 and Neo-DIN (Germany), ASA PH 2.5.1954 (USA), BS 1380.1947 (Great Britain), Z 7.0.2.2.1951 (Canada), ISO Recommendation, AFNOR-SOF PR-C20-002 (France), NSG FISK 7604–1954 (Japan), 1940 (15) (Holland), and RN-53/C.U.K-P.00012, P.0003 (Poland).

The conditions of exposure, development, and density measurement are of considerable importance in obtaining the characteristic curve. Incandescent light sources with liquid Davis-Gibson daylight filters are used in all standards except those of the USSR and Holland. The Russian standard calls for a solid glass daylight filter and the Dutch are using a light source which is a mixture of monochromatic bands in the range of 330–700 mμ. A neutral gray scale with a gradient of 0.10 or 0.15 per step is used, mostly with an exposure duration of approximately 0.05 sec. In some cases, the exposure is shorter or longer, reflecting the normal use of particular photographic materials. Developing is done under strict standardization of time, temperature, and agitation and with regard to gamma or contrast for specific films like sound recording or line copy. Developing solutions are of composition very close to those currently suggested by manufacturers for particular materials. All standards specify diffuse density measurement using an opal glass diffuser over the densitometer light source or an integrating light collector with wide angle of acceptance. A table collates the following items in these standards: field of application, light source, method of exposure, method of development, measurement of density, speed criterion, and method of expressing speed. The American, British, and Canadian standards use the fractional gradient criterion for speed. The other six standards determine the speed by the exposure necessary to obtain a density of 0.1 or 0.2 above the fog level.

The Cinematography of Internal Flow of Metal During Rolling Operations

O. G. Muzalevskii. Pp. 363–67

This new method is based on rapid-sequence multiple exposures made during rolling operations of specially prepared mill samples. A 35mm reflex camera was modified by addition of the motor-driven slit-shutter back of a 400mm telephoto lens. Samples of metals with specially drilled holes tapering inwards were used for the study. The camera lens forms multiple images of the shape of the holes and analysis of the images provides flow data on the rolling operation.

Investigation of Free Flight of Cereal Grains by Means of High-Speed Cinematography

A. A. Kukibnyi and V. A. Smorodin. Pp. 368–76

Air currents are often used to move cereal grains distances up to 60 ft in operations such as cleaning, sorting, drying, cooling, loading, and unloading. This paper discusses a photographic method of investigating the kinetics of these operations. The authors conclude that future work will have to be done in stereo.

The Influence of Light Sources on the Resolving Power of Motion-Picture Duping

I. I. Breido and L. V. Kruglyakova. Pp. 359–62

The use of ultraviolet light sources for printing has

been suggested before. The work reported here substantiates the advantages of short wavelengths as printing sources, especially the use of collimated ultraviolet. Starting with a duplicate positive of 200 lines/mm, the authors were able to produce a third-generation release positive of 56 lines/mm on ordinary duplicating materials using collimated ultraviolet, compared with 37 lines/mm obtainable on high-resolution film "Mikpat" using collimated incandescent light.

(*Editor's Note:* Other papers in the September-October issue of the *Zhurnal* . . . will be reported in the next issue of *P S & E*.)

Journal of the Society of Scientific Photography of Japan. Vol. 21, No. 1, March 1958

Physical Chemistry of Optical Sensitization and Desensitization

HIROSHI HADA. Pp. 1–10

This is primarily a review paper which discusses adsorption of the dyes, absorption of light by the adsorbed dyes, energy transfer from the excited dye molecule to the silver halide, and the desensitizing action of the dyes in terms of the nonlocalized π-electrons and the planarity of the dye molecules.

Latent Image Fading in Gammagraphy

YOSHITADA TOMODA and NOBUYA NAKAMURA. Pp. 16–19

The results of numerous investigations on the fading of latent images in nuclear track emulsions have been published in recent years but little information on the fading of latent images produced by gamma rays has appeared. Tomoda and Nakamura have made a comparison of the fading of latent images produced by gamma rays from Cobalt 60 and by light in commercial x-ray films, process plates, and negative films. The exposed materials were kept at 30° C and 43% or 68.6% relative humidity for various times up to 30 days before development. The fading rate was higher at the higher humidity, in agreement with results found by other workers for latent images in nuclear emulsions. Grain size as such does not appear to be a determining factor in latent image fading. X-ray films and process plates which showed high latent-image fading for gamma-ray exposures also showed high rates of fading for light exposures; the light images do not appear to be necessarily more stable than the latent images produced by high energy radiation. Surface latent images faded more rapidly than internal latent images for both gamma-ray and light exposures.

Topochemical Aspects of Chemical Sensitization of the Photographic Emulsion

EIICHI MIZUKI and SHIN FUJISAWA. Pp. 11–15

In experiments on the etching of chemically sensitized emulsion grains with various solvents, it was observed that a large decrease in sensitivity for high intensity exposures could be obtained under conditions which did not appreciably change the sensitivity to low intensity exposure. Apparently when the sensitizing material was isolated from the grain surface by the solvent action it lost its ability to sensitize surface image formation by high intensity exposures, but still remained effective as a sensitizer for low intensity exposures. The authors suggest that finely dispersed sensitizing material in the silver gelatinate envelope surrounding the grain can be effective for low intensity exposure, probably by acting as a halogen acceptor, but only sensitizer on the grain surface is effective for high intensity exposure. An English version of this paper appeared in *Photographic Sensitivity*, Vol. 2, Tokyo Symposium (see *P S & E*, 2:234 (1958)).

Characteristics of Photographic Materials for Electron-Beam Exposures. II. A Method of Measuring Sensitivity and Gradation

MATAICHI TAJIMA. Pp. 24–32

A method of sensitometry is described for materials used in the electron microscope. — *T.H.J.*

Optical Sensitization of the Photographic Process

Under this title, William West reviews the theory of optical sensitization and reports a preliminary result on an interesting approach to the problem of how the absorption of a quantum of radiation by the sensitizing dye introduces a mobile electron and a positive hole into the silver halide crystal. Two types of mechanism have been proposed, one involving the transfer of energy from the dye molecule to the crystal, the other involving the transfer of an electron. No direct, decisive experiment has yet been made, although observations by Nelson on contact potential differences between dyes and silver halides seem consistent with an electron transfer mechanism. West points out that if electron transfer does occur the dye molecule would temporarily be left as a paramagnetic free radical which might be detected by measurements of paramagnetic electron resonance. Preliminary measurements made at room temperature gave negative results, but these results only show that a free radical which has a lifetime of a few milliseconds or more at room temperature is not formed. A definite conclusion must be reserved until low temperature measurements can be made, where any free radicals which might be formed would have a longer lifetime.

Under some conditions of sensitization, exciton propagation within the layer of adsorbed dye occurs, and foreign molecules, acting as exciton traps, may cause important increases in the efficiency of transfer to the silver halide. This is the mechanism of supersensitization. Its opposite, antisensitization, also is observed when the foreign molecules decrease the transfer efficiency. — *T.H.J.*

References: R. C. Nelson, *J. Opt. Soc. Am.*, *46*:1016–19 (1956); W. West, *J. chim. physique*, *55*:672–80 (1958).

• Technicalia Photographica

FRANK SMITH

• Cameras and Projectors

Avco Rotating Mirror and Rotating Drum Cameras

Two laboratory standard instruments — rotating mirror and rotating drum cameras — for photographic recording of high-velocity phenomena have been developed by Avco Manufacturing Corporation's Re-Research and Advanced Development Division, Wilmington, Mass. The devices are valuable in studies of transient events which emit or reflect light.

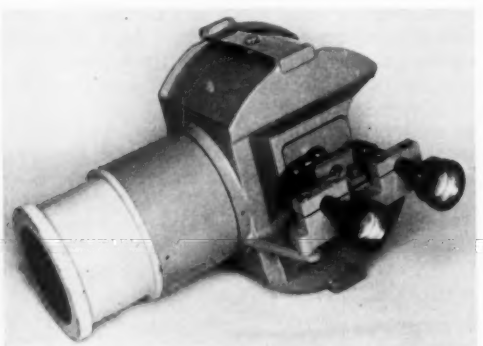
The cameras were developed and used in research on high-temperature gas dynamics and atmospheric re-entry problems in the Air Force Titan intercontinental ballistic missile program.

The rotating mirror camera (illustrated) records position versus time relationships, sweeping the image from a hypersonic object source onto high-emulsion-speed film strips. Heart of the unit is a hexagonal, first-surface mirror, rotating at 3000 rps, which provides a writing speed of 4mm/μsec for a total writing time of 50 μsec. Other components are a cast aluminum main housing, $f/2.5$ lens, two curved film holders, and air turbine drive.

The rotating drum camera, in addition to making position-time film records, also may be used with a densitometer to produce accurate data of high-velocity phenomena. In conjunction with a Schlieren system, it will produce microsecond-order photographic frames for graphic analysis. It is said that a precision-manufactured, dynamically balanced drum, rotating at 600 rps provides a writing speed of 0.19mm/μsec and a total writing time of 1667 μsec. The high-emulsion-speed film is fixed to the inner periphery of the drum.

Both cameras operate on compressed air, directed through shaped nozzles at turbines integral with either the rotating mirror or drum units. It is claimed that the advantages of only one moving part and the one pre-operational adjustment of focus, which is set and locked, make the Avco cameras inherently simple and reliable.

For data reduction, both cameras provide continuous optical records which are readily measurable. Constant focal distances and known rotational speeds of the mirror and drum permit accurate calculation of velocities.



Sampson-Hall Professional Underwater Motion-Picture Camera Housing

Sampson-Hall Co., 7268 Franklin Ave., Hollywood 46, Calif., has developed a standard 16 model professional underwater camera housing which accommodates Bell & Howell 16mm cameras, Models 70-DL and 70-DA, and Model 70 when converted. The standard housing is calibrated for the Elgeet 13mm wide-angle $f/1.5$ lens.

The housing is cast of high-grade aluminum alloy, heat treated to withstand external pressures, machined to close tolerances, and then treated against the corrosive action of salt water. All control seals are run on precision chrome surfaces in removable retainers.

The housing is described as streamlined and perfectly balanced. There are two large ports, front and rear, to permit through vision. Two molded pistol-grip handles provide for a steady camera. The wind handle is on the right. On the left is the f-stop control lever which controls the lens aperture settings

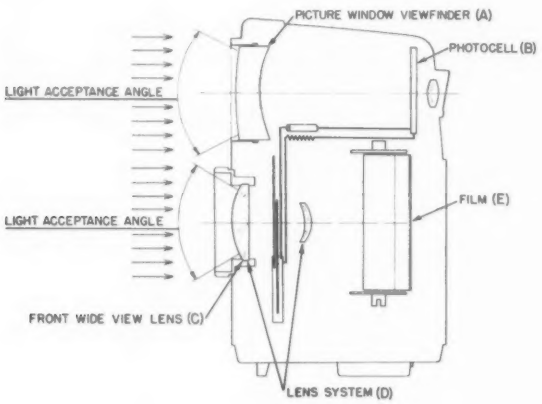
and the large sweep indicator hand over the *f*-stop calibrations on the rear port. It is operated by the left thumb.

By removing six lug nuts, the camera and rear section can be removed from the main housing and used for picture taking, and by removing one bolt the camera may be separated from the rear section. It is not necessary to pressurize at depths of less than 150 ft. At more than that depth, the housing may be pressurized through the valve in the rear section.

The camera and housing weigh approximately 25 lb in air, but under water they are only a few ounces.

Bell & Howell "Infallible" Electric Eye Still Camera

A completely automatic still camera has been introduced by Bell & Howell Company, 7100 McCormick Rd., Chicago 45, Ill. The camera, called the "Infallible," does not require manual exposure setting or focusing. A photocell or "electric eye" computes the light reading and sets the lens opening, leaving the photographer free to sight and shoot. The lens requires no focusing.



As the photographer sights and shoots, light striking the photocell generates an electric current which sets the lens for correct exposure. The action is continuous and instantaneous. The lens adjusts to light changes faster than the human eye and continues to adjust whenever light reaches the photocell.

The camera uses No. 127 roll film, 12 exposures to the roll. The housing is sturdy, die-cast aluminum. Dimensions are $3^3/_4$ in. wide, $2^7/_8$ in. deep, and $4^5/_8$ in. high, and weight of the camera is 24 oz.

Pinhole Camera

A pinhole camera for mapping beta-active deposits has been constructed by the Physics Department of the Edsel B. Ford Institute for Medical Research, Detroit, Mich.

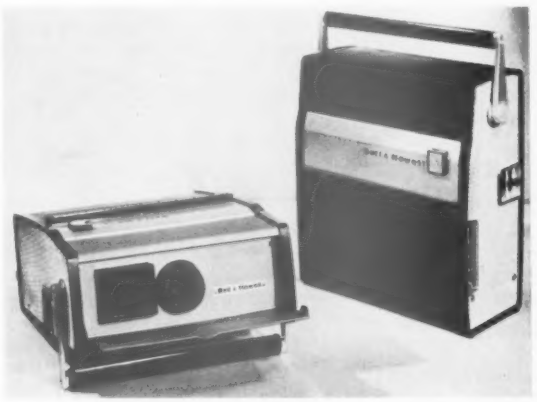
The camera, which is essentially an evacuated cylinder, permits continuous adjustment of aperture and film position. It is equipped with a cassette designed to hold a wide range of film and plate sizes and a shutter permits loading and adjustment before exposure.

The camera is described in some detail by L. E. Preuss and G. Jenkins in an illustrated article appearing in *Nucleonics* for October 1958, pp. 98–99.

Bell & Howell "Explorer" Series Slide Projectors

Automatic slide projectors of modern, "slim-line" design, requiring no case or cover removal for immediate projection, have been announced by Bell & Howell Company, 7100 McCormick Rd., Chicago 45, Ill.

The new projectors have swing-down front and rear panels, illuminated "dashboard" controls at the back



of the machine, and a remote control system that permits slides to be moved in reverse as well as forward.

Four new models using 300 or 500-w lamps are included in the "Explorer" series. All models permit slides to be rearranged while the tray is in the projector.

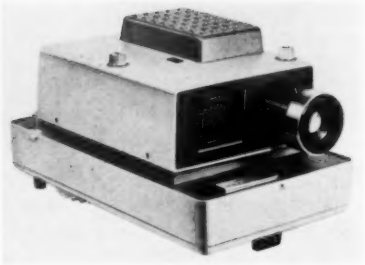
Argus "President" Color-Slide Projector

A 500-w color-slide projector that is fully powered for completely automatic forward and reverse operation as well as for elevation and other controls has been announced by Argus Cameras, a division of Sylvania Electric Products, Inc.

The "President" has a light-intensity control to adjust the screen brightness for individual slides; knob focusing; and a tilt adjustment knob supplementing the power-operated elevation control for leveling the picture.

A timer permits automatic showing of 36 slides by preselection of one of six slide-screening intervals, ranging from 5 to 60 sec, on the projector's electronic control panel.

Remote control operation also is possible at distances up to 15 ft from the projector. A convenient slide-viewing window on the back of the projector makes possible "previewing" of the slides as they are



placed in the slide tray. The slides, preconditioned for constant focus, then may be screened in normal forward fashion, or in reverse order, through use of a slide-tray direction-selector control.

The all-metal President comes with carrying case, slide tray, single-slide adapter, and remote-control cord. The optical system has a 5-in. Argus three-element $f/3.3$ lens and the 500-w Sylvania "Tru-Focus" projection lamp.

Beckman and Whitley Continuous-Writing Framing Camera

Recording 82 35mm frames for a 55-μsec period, the new Model 192 Continuous-Writing Framing Camera is designed to accommodate magnification-velocity products up to 3mm/μsec, or at conventional magnification, object velocities to Mach 35. It is offered by Beckman and Whitley, Inc., 973 E. San Carlos Ave., San Carlos, Calif.

Complementing the specifications of the Model 189 Framing Camera, the new instrument operates with no blind time, which means that it can be used to photograph high-speed events which do not lend themselves to synchronization with the position of the rotating mirror in the camera. Because of this, the Model 192 is said to be applicable to high-speed aerodynamic studies, for thermal-barrier studies in ballistic investigations (such as nose-cone re-entrance problems), for hypersonic wind tunnel instrumentation, and for exploring the behavior of rocket propellants, etc.

Supplied complete with operating controls, the Model 192 has bore-sight optics and rack-and-pinion focusing arrangements. Daylight loading and unloading are provided for with standard 35 mm film cassettes. The camera itself weighs 1800 lb and measures 84 × 60 × 36 in.

High-Speed Framing Disk Camera

C. H. Bagley of the Poulter Laboratories, Stanford Reseach Institute, Menlo Park, Calif., writing in the *Review of Scientific Instruments* for October 1958, describes and discusses a high-speed framing camera designed to investigate problems requiring a time coverage of 6 to 20 msec.

A unique feature of the camera is that it combines the short exposure times of the rotating mirror framing cameras with a rotating disk which is used as a film transport. The author claims that 60 pictures at rates up to 15,000 frames/sec are possible. An important feature of the camera is the large image size ($^5/_8$ in. × $1^1/_4$ in. or $^3/_8$ in. × $1^1/_4$ in., depending on the frame rate required). An exposure time of 0.2 μsec has made the camera useful in a number of applications.

The camera is air turbine driven and no synchronization is required, but the speeds of the rotating mirror and the disk drive must be preset.

• Illumination

Three New GE Projection Lamps

The Photo Lamp Department of General Electric Co., Nela Park, Cleveland 12, Ohio, has announced three new projection lamps with internally mounted mirrors intended to eliminate the need for separate reflectors and result in brighter pictures, since the mirrors are protected by the lamp envelope from discoloration caused by the atmosphere.

All the lamps are 500-w, have four-pin base, and are gold-topped. One is designed primarily for 8mm movie projectors, while the other two may be used in slide or movie projectors.

The new lamps are designated DHJ, CZA, and DFR. In the DHJ "non-axial" type, a small flat mirror directly above the filament bounces the light to a larger curved mirror. The larger mirror, set at an angle to the lamp's axis, collects the light and redirects it out of the lamp. Its concentrated beam focuses near the film.

The CZA has a single reflector, a half-inch square, of bright metal.

The DFR lamp is similar to the CZA except that it can be operated horizontally as well as vertically. In addition, it has a locking-type pin base and a screen above the mirror and filament which prevents bulb blackening in the light path.

Luminescence and Luminescent Materials

D. G. Anderson, *Jour. Electronics and Control, First Series*, 5:457–70 (1958).

A general review of luminescent materials is given with some emphasis on the more recent applications. The theoretical aspects of the absorption and emission processes are discussed briefly. Illus., 6 ref.

New Combustible Photoflash Lamps

L. F. Anderson, *Illum. Eng.*, 53: 657–63 (1958).

The development of the new zirconium photoflash lamps is described, including theoretical considerations, preparation of materials, and test program. The reasons for the selection of zirconium are given, and the somewhat involved processing of zirconium into suitable raw material for photoflash lamps is outlined. The advantages of zirconium, as well as the advantages obtained from the particular designs selected, are discussed. Performance characteristics, including light output, timing, color temperature, and reflector efficiency are described and illustrated. Reasons for choosing the rated peak times specified, as well as other ratings, and the photographic significance of this development are discussed.

• Processing Equipment and Techniques

National X-Ray Products Corp. Automatic Film Drier

A stainless steel drier with a total capacity of 18 films of any size up to 14 × 17 in. has been announced by the Spindex Division of the National X-Ray Products Corp., 71 S. Newman St., Hackensack, N.J.

It is claimed that the drier cuts film drying time to 3 to 5 min. The drier is self-contained, requiring no external ducts or plumbing connections.

New Fisher Microfilter

Intended primarily to meet the needs of industrial, professional, and commerical photographers, the compact Fisher Microfilter is said to be useful wherever positive filtration is required. The Oscar Fisher Co. of Newburgh, N.Y., has designed the Microfilter without screens and pads, and has installed a permanent-type filter element employing the sintered-metal

principle. The all-metal filter may be connected by using standard half-inch pipe fittings, and it has a three-way reversing valve and a petcock to facilitate flushing.

The Microfilter can be cleaned by reversing the flow of water momentarily, without the stoppage of any work. Where larger quantities of water are required, two Microfilters can be installed in parallel.

• Miscellaneous

Air Force Opto-Electronic System

A technical note in *Missiles and Rockets* for Dec. 1, 1958 (pp. 35–36), gives a few details of the Air Force's newest camera pickup tube which is three to four times more sensitive to white light than tubes previously used for telescopes.

The opto-electronic system was conceived by Radames K. H. Gebel, civilian scientist at the Wright Air Development Center's Aeronautical Research Laboratory, Dayton, Ohio, and was perfected by the Westinghouse Electric Corp., Electronic Tube Div., Elmira, N.Y.

The new tube has already been used with a telescope at Wittenberg College to produce a composite photograph made up of more than 200 separate pictures of the full moon. The composite picture is 40

in. in diameter and is said to show details invisible with ordinary photographic methods.

Essentially, the opto-electronic system is a closed circuit TV system. The telescopic images picked up by the system are transformed into electrical impulses in the camera tube and these are made visible on the face of a cathode-ray tube after passing through a video amplifier. The images appearing on the face of the tube are then photographed by conventional means.

Vanguard Model C-11D Projection Case

Model C-11D Projection Case is now available for use with the standard line of Vanguard Projection Heads, according to an announcement from the Vanguard Instrument Corp., Roosevelt, L.I., N.Y.

The C-11D Projection Case has an 11-in. diameter screen and is suitable for automatic X-Y, angle, and frame-count readings directly to IBM card punch or Clary printer systems. Projection heads for 8, 16, 35, or 70mm film are available. After manually positioning the crosshairs and angle screen on an object in the viewed image, the operator presses a button which automatically reads out the data.

Coordinate readout is in increments of 0.001 in. at the magnified screen image, and angle measurement is to 0.10 deg.

Kodak Lenses, Shutters, and Portra Lenses

A revised (6th) edition of the Kodak Data Book with the above title has been published by the Eastman Kodak Company.

The illustrated 56-page book explains how a camera lens transfers the subject image onto the film and how the camera lens and shutter work together to produce a sharp image of the subject at various distances.

A new section explains the recently adopted exposure value system. Also of interest is the section containing data on the lenses and shutters with which Kodak amateur still cameras are equipped.

A New Approach to the Calibration of Photographic Equipment and Materials

Jan A. Van Den Broek, *The Sylvania Technologist*, *11*:132–39(1958).

The origin and meaning of conventional calibrations on photographic equipment and materials are discussed. A new system of calibrations, based on logarithms of the pertinent quantities, is described, and the advantages of this system in simplifying camera operation and exposure determination are discussed. Ref., illus.

1959 Annual Conference

26 to 30 October 1959

Edgewater Beach Hotel · Chicago, Illinois

The next National Conference of the Society has been scheduled for October 26 through 30, 1959, at the Edgewater Beach Hotel, Chicago, Ill. Planning for the Conference is well under way.

An extensive papers program is being prepared under the guidance of Charles E. Ives, Papers Chairman, Research Laboratories, Eastman Kodak Company, Rochester 4, N.Y. There will be exhibits of special photographic instruments and equipment. Exhibits Chairman is Arthur E. Neumer, Jr., Hawk-Eye Works, Eastman Kodak Company, 20 Avenue E, Rochester 21, N.Y. Conference Coordinator is Ira R. Kohlman, Colorfax Laboratories Inc., 1160 Bonifant St., Silver Spring, Md.

The Society of Photographic Scientists and Engineers

Box 1609 • Main Post Office • Washington, D.C.

OFFICERS

President	GEORGE T. EATON, Building 59, Kodak Park, Rochester 4, New York
Executive Vice President	STEVEN LEVINOS, Ansco, Binghamton, New York
Engineering Vice President	JOHN A. MAURER, 116–118 West 29th Street, New York 1, New York
Editorial Vice President	PETER KRAUSE, 295 Riverside Drive, Johnson City, New York
Financial Vice President	HERBERT MEYER, 325 Sequoia Drive, Pasadena 2, California
Secretary-Treasurer	NORTON GOODWIN, 826 Connecticut Avenue NW, Washington 6, D.C.
Managing Secretary	EDWARD S. COBB, Box 1609, Main Post Office, Washington, D.C.

CHAPTERS *and* CHAPTER OFFICERS

Binghamton, New York	*President*	IRA B. CURRENT, 26 Woodland Avenue, Binghamton, New York
	Secretary	E. SCUDDER MACKEY, Stone Road, RD No. 2, Binghamton, New York
Boston, Massachusetts	*President*	NICHOLAS CEDRONE, 73 Pond Street, Waltham, Massachusetts
	Secretary	ARTHUR J. ROSENBAUM, 44 Gleason Street, Framingham, Massachusetts
Cleveland, Ohio	*President*	R. E. BIRR, c/o General Electric Lamp Division, Nela Park No. 281, Cleveland 12, Ohio
	Secretary	CLINTON K. HAMLINK, 2230 South Overlook Road, Cleveland 6, Ohio
Ithaca, New York	*President*	COLONEL WILLIAM ALLEN, 216 Forest Home Drive, Ithaca, New York
	Secretary	DAVID O. FLETCHER, 1314 East State Street, Ithaca, New York
Monmouth, New Jersey	*President*	JOSEPH MANGIARACINA, 30 Brook Avenue, Little Silver, New Jersey
	Secretary	MISS MARILYN LEVY, 100 McLaren Street, Red Bank, New Jersey
New York, New York	*President*	FRANK G. BACK, 55 Sea Cliff Avenue, Glen Cove, New York
	Secretary	LT. HAYDEN B. PEAKE, Army Pictorial Center, 35-11 35th Avenue, Long Island City 1, New York
Rochester, New York	*President*	DONALD B. GRIM, Building 29, Eastman Kodak Company, Rochester 4, New York
	Secretary	ROBERT W. MAHER, Eastman Kodak Company, 343 State Street, Rochester 4, New York
Southern California	*President*	CLAYTON S. CHAPEN, 652 Calle Miramar, Redondo Beach, California
	Secretary	ROBERT J. KEIDATZ, 7519 Baird Avenue, Reseda, California
Southern Lake Michigan	*President*	HENRY COOPMAN, 9118 Greenwood Avenue, Ballard Acres, Des Plaines, Illinois
	Secretary	ROBERT J. MAZOR, 1438 West 123rd Street, Chicago 43, Illinois
Washington, D.C.	*President*	DWIN R. CRAIG, 815 Fisher Street, Falls Church, Virginia
	Secretary	LEE M. RECORDS, 1335 Tewksbury Place NW, Washington, D.C.

Sustaining Members / Society of Photographic Scientists and Engineers

Abrams Instrument Corporation

Aero Service Corporation

Ansco Division, General Aniline & Film Corporation

Atkinson Laboratory, Incorporated

Bar-Ray Products, Incorporated

Bausch & Lomb Optical Company

Bell & Howell Company

Charles Beseler Company

Burke & James, Incorporated

Chemco Photoproducts Company, Incorporated

Chicago Aerial Industries, Incorporated

Consolidated Film Industries

E. I. du Pont de Nemours & Company

Eastman Kodak Company

Edgerton, Germeshausen & Grier, Incorporated

The EdnaLite Optical Company, Incorporated

Elgeet Optical Company, Incorporated

Fairchild Camera & Instrument Corporation

Farrand Optical Company, Incorporated

Oscar Fisher Company, Incorporated

The F-R Corporation

General Electric Company

General Film Laboratories Corporation

Graflex, Incorporated

Grant Photo Products, Incorporated

W. & L. E. Gurley Company

Haloid Xerox Incorporated

Hardale Associates

Hi-Speed Equipment, Incorporated

Houston Fearless Corporation

Charles A. Hulcher Company, Incorporated

Philip A. Hunt Company

Hycon Manufacturing Company

The Kalart Company, Incorporated

Kollmorgen Optical Corporation

LogEtronics Incorporated

L-W Photo Products Company

J. A. Maurer, Incorporated

The Morse Instrument Company

National Research and Chemical Company

North American Aviation, Incorporated

Pako Corporation

Photogrammetry, Incorporated

Polaroid Corporation

Rolor Industrial Corporation

Simmon Brothers, Incorporated

Technicolor New York Corporation

Tiffen Marketing Company

Viewlex, Incorporated

Wollensak Optical Company

Zoomar, Incorporated